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WATER RESOURCES DEVELOPMENT IN AFRICA: A REVIEW AND SYNTHESIS OF ISSUES, POTENTIALS, AND STRATEGIES FOR THE FUTURE

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ABSTRACT

This paper analyzes how water resources development and water policy reform can be deployed to address the twin problems of food insecurity and water scarcity in Africa and, in particular, Sub-Saharan Africa. The paper reviews the current status of water supply and demand, and the existing and potential irrigated land base in Africa; reviews the performance of existing irrigation systems and assesses the magnitude of the potential contribution and cost-effectiveness of new irrigation development to future food production in Africa; and explores the potential for water conservation through demand management. Meeting the challenges of food security and water scarcity in Africa will require both selective development and exploitation of new water supplies and comprehensive policy reform that encourages efficient use of existing supplies. The most significant reforms will involve changing the institutional and legal environment in which water is supplied to one that empowers water users to make their own decisions regarding the resource. Irrigation development will not be the main source of food production growth in Africa, but increased investment in irrigation could have an important role in reducing projected cereal import demands. Rehabilitation and improvement of existing irrigation systems can be an attractive option, but projects must be selected carefully.

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1. INTRODUCTION

Inadequate growth in food production and increasingly scarce water pose serious constraints to future agricultural and economic development in Africa, particularly in Africa south of the Sahara. Global food projections indicate that, although the aggregate global food supply/demand picture is relatively good, with food production in the world growing fast enough for world prices of food to be falling, there will be a worsening of food security in Sub-Saharan Africa (Rosegrant, Agcaoili-Sombilla, and Perez 1995). In this region, cereal imports are projected to triple, from 9 million metric tons in 1990 to 29 million metric tons in 2020. Sub-Saharan Africa will not have the financial means to pay for these growing imports. The international community will need to devise appropriate combinations of financing and food aid to bridge these food gaps for the foreseeable future. Of even greater concern, the number of malnourished children is projected to increase by 14 million by 2020 in Sub-Saharan Africa. Thus, even with relatively abundant food in the world, there will not be enough growth in effective per capita food demand in Sub-Saharan Africa to improve the food supply situation. Although the food situation is less severe in North Africa, increasing cereal imports up to 2020 are also projected for this region.

The growing food supply problems in the region are compounded by increasing water scarcity. Countries are considered water scarce when annual internal renewable water resources are less than 1,000 cubic meters per capita per year. Below this threshold, water availability is considered a severe constraint on socioeconomic development and environmental quality. Currently, some 28 countries with a total population of 338 million

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are considered water stressed, and 20 of these countries are water scarce, 9 of them in Africa (Engelman and LeRoy 1993). By 2020, it is likely that the number of water-scarce countries will approach 35, and the number of water-scarce African countries could double to 18. Many other African countries, which may have adequate water in the aggregate, suffer from debilitating seasonal and regional shortages which urgently need to be addressed.

2. OBJECTIVES

The primary objective of this paper is to examine, based on a review and synthesis of available material, how water resources development and water policy reform can be deployed to address the twin problems of food insecurity and water scarcity in Africa. The paper will review the current status of water supply and demand in Africa; summarize the existing and potential irrigated land base; assess the magnitude of the potential contribution of irrigation development to future food production in Africa; review the performance record of existing irrigation systems; analyze the cost-effectiveness of development of new irrigation and water resources; and explore the potential for conserving water through demand management. Based on this analysis, appropriate irrigation investment strategies and water policies will be identified.

3. TRENDS IN WATER SUPPLY AND DEMAND IN AFRICA

Per capita water availability by regions of the world is summarized in Table 1. Per capita water availability is highest in South and North America, while Africa, Asia, and Europe have far less water per capita. Countries with freshwater resources in the range 1,000-1,600 cubic meters per capita per year face water stress, with major problems occurring in drought years. Countries are considered water scarce when annual internal renewable water resources are less than 1,000 cubic meters per capita per year. Below this threshold, water availability is considered a severe constraint on socioeconomic development and environmental quality. The aggregate water availability in Africa of 9,400 cubic meters per capita per year in 1980 shown in Table 1 suggests ample water supplies, but these aggregate regional figures hide the huge variability in water availability within the region.

Table 1 Per capita water availability by region, 1950-2000

Region	1950	1960	1970	1980	2000
			(thousand cubic meters)		
Africa	20.6	16.5	12.7	9.4	5.1
Asia (excluding Oceania)	9.6	7.9	6.1	5.1	3.3
South America	105.0	80.2	61.7	48.8	28.3
North & Central America	37.2	30.2	25.2	21.3	17.5
Europe (excluding the Soviet Union)	5.9	5.4	4.9	4.6	4.1

Source: Ayibotele 1992.

Table 2 shows the wide variability in water resource availability for regions in Africa. Nearly one-half of the water resources in Africa are concentrated in the Central region, while only about 4 percent are in the Sudano-Sahelian area and about 1 percent in Northern Africa. All North African countries are water scarce or water-stressed, including Tunisia, with 540 cubic meters per capita; Algeria, with 690 cubic meters; Libya, with 1,017 cubic meters; Morocco, with 1,151 cubic meters; and Egypt, with 1,046 cubic meters per capita. Several Sub-Saharan African countries are also water scarce, including Burundi and Kenya, with 654 and 635 cubic meters of water per capita, respectively; and Malawi, Rwanda, and Somalia, all between 900 and 1,000 cubic meters per capita. At the other extreme are several countries, such as Gabon, Liberia, and Zaire, which have over 20,000 cubic meters per capita of freshwater (Engelman and LeRoy 1995).

Per capita water supplies in Africa are projected to drop by 45 percent between 1990 and 2000 (Table 1). Tightening supplies will be accompanied by rapid growth in water demand. Water use by region since 1950 is summarized in Table 3. In 1990, Asia accounted for 60 percent of world water withdrawals, North America for 17 percent, Europe for 13

Table 2 Regional distribution of water resources

	Area (1000 km^2)	Precipitation (km^3/yr)	Internal renewable resources			
			(km^3/yr)	(mm/yr)	As % of total	As % of precipitation
Northern	5,753	411	50	8.7	1.2	12.2
Sudano-Sahelian	8,591	2,878	170	19.8	4.3	5.9
Western	2,106	2,965	952	452.0	23.8	32.1
Central	5,329	7,621	1,946	365.2	48.8	25.5
Eastern	2,916	2,364	259	88.8	6.5	11.0
Islands (I.O.)	591	1,005	340	575.3	8.5	33.8
Southern	4,739	2,967	274	57.8	6.9	9.2
Total	30,025	20,211	3,991	132.9	100.0	19.7

Note: The regions are:

Northern: Algeria, Egypt, Libya, Morocco, and Tunisia.
Sudano-Sahelian: Burkina Faso, Cape Verde, Chad, Djibouti, Eritrea, Gambia, Mali, Mauritania, Niger, Senegal, Somalia, and Sudan.
Western: Benin, Côte d'Ivoire, Ghana, Guinea, Guinea Bissau, Liberia, Nigeria, Sierra Leone, and Togo.
Central: Angola, Cameroon, Central African Republic, Congo, Equatorial Guinea, Gabon, São Tome and Principe, and Zaire.
Eastern: Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda.
Indian Ocean Islands: Comoros, Madagascar, Mauritius, and Seychelles.
Southern: Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe.

Source: FAO 1995a.

Table 3 Water use by continent

	1950	1960	1970	1980	1990	2000
	(cubic kilometers per year)					
Africa	56	86	116	168	232	317
Asia	865	1,237	1,543	1,939	2,478	3,187
Latin America	59	63	85	111	150	216
North America	286	411	556	663	724	796
Europe	94	185	294	435	554	673
Total	1,360	1,982	2,594	3,316	4,138	5,189

Source: Clarke 1993.

percent, Africa for 6 percent, and Latin America for 4 percent. Water demand in Africa has grown rapidly, at 3.5 percent per year since 1970, considerably faster than the 2.4 percent growth rate for the world as a whole.

Water use can be divided into three major categories: agriculture, industry, and domestic. Domestic use includes drinking water, private homes, commercial establishments, public services, and municipal supplies. Agriculture is by far the biggest water user, accounting for over 85 percent of water withdrawals in Africa (Table 4). However, although agriculture accounts for by far the largest share of water, the growth in demand for water in North Africa is much higher for domestic and industrial uses (World Bank 1993). Although time series data are limited, high growth rates of non-agricultural water demand are also expected in Sub-Saharan Africa, due to rapid urbanization.

4. TRENDS IN IRRIGATED AGRICULTURE

IRRIGATION POTENTIAL

Although agriculture is by far the biggest water user in Africa, the full physical irrigation potential is far from being tapped. Only about one-third of the potentially irrigated area is under irrigation. Physical potential is only limiting in North Africa, where almost three-fourths of the irrigation potential has already been used. More than one-third of the potential area is being irrigated in the Southern and Indian Ocean Islands, and the Sudano-Sahelian regions, and less than 10 percent in the Western, Central, and Eastern regions (Table 5).

While these numbers appear to suggest dramatic potential for future expansion, much of the potential area is in regions with abundant rainfall, (or with wetlands or flood recession irrigation), where irrigation systems are unlikely to have high economic payoffs. Mean annual rainfall ranges from a few millimeters in the central Sahara to several meters in parts of the humid tropical zone of West Africa. Potential evapotranspiration ranges from under 1,500 millimeters per year in more humid areas to between 2,000 and 2,500

Table 4 Regional distribution of water withdrawals in Africa

Region	Withdrawals by sector					
	Agriculture	Municipal	Industries	Total	As % of total	As % of internal resources
			($x10^6 m^3$/yr)		*(percent)*	
Northern	65,000 (85%)	5,500 (7%)	5,800 (8%)	76,300 (100%)	50.9	152.6
Sudano-Sahelian	22,600 (94%)	1,200 (5%)	300 (1%)	24,100 (100%)	16.1	14.2
Western	3,800 (62%)	1,600 (26%)	700 (12%)	6,100 (100%)	4.1	0.6
Central	600 (43%)	600 (43%)	200 (14%)	1,400 (100%)	0.9	0.1
Eastern	5,400 (83%)	900 (14%)	200 (3%)	6,500 (100%)	4.3	2.5
Islands (I.O.)	16,400 (99%)	200 (1%)	20 (-)	16,620 (100%)	11.1	4.9
Southern	14,100 (75%)	3,000 (16%)	1,800 (9%)	18,900 (100%)	12.6	6.9
Total	127,900 (85%)	13,000 (9%)	9,020 (6%)	149,920 (100%)	100.0	3.8

Source: FAO 1995a.

Table 5 Actual and potential irrigation in Africa by region

Region	Potential '000 ha	Irrigated '000 ha	Irrigated as % of arable	Irrigated as % of total	Irrigated as % of potential
Northern	8,130	5,915	24.8	48.6	72.8
Sudano-Sahelian	7,716	2,484	10.4	20.4	32.2
Western	8,200	470	1.3	3.9	5.7
Central	13,320	121	1.0	1.0	0.9
Eastern	5,364	434	1.9	3.6	8.1
Southern and Islands (I.O.)	7,481	2,750	10.7	22.6	36.8
Total	50,211	12,174	8.5	100.0	24.2

Source: FAO 1995a.

millimeters per year in semi-arid and arid zones. Nearly all of North Africa can be characterized as arid, with irrigation essential for agriculture.

CLIMATE

The climate of Sub-Saharan Africa can be very broadly divided into three major zones:

(1) The humid tropical zone. Mean annual rainfall exceeds 1,200 millimeters and is usually over 1,500 millimeters. Rain is fairly well distributed, seldom with more than 4 dry months. The growing period for annual crops usually exceeds 280 days per year. Irrigation is only economically justified for dry-season supplementation of some perennial crops.

(2) The savannah zone. Mean annual rainfall is between about 800 and 1,200 millimeters. Within-season rainfall patterns as well as seasonal totals are highly variable; the growing period for annual crops ranges from 120 to 240 days. Below 200 days drought-related crop failure increases. Supplementary irrigation can compensate for within-season dry spells, even in average rainy seasons. Irrigation is essential for dry-season annual cropping and for many perennial crops.

(3) The semi-arid/Sahelian zone. Mean annual rainfall is below 800 millimeters and can be below 100 millimeters. Rainfall is erratically distributed within the rainy season. Up

to 20 percent of annual rainfall may occur within a single day, causing heavy runoff and soil erosion. The growing season for annual crops is below 100 days in much of the zone. Irrigation is essential for crop production and low-intensity grazing is the traditionally preferred land use (FAO 1986).

Eight Sub-Saharan countries (Botswana, Burkina Faso, Kenya, Mali, Mauritania, Niger, Senegal, and Somalia) have little or no land with a rainfed growing period above 200 days and cannot meet their food demand needs from low-input rainfed farming. Together they contain almost 14 percent of the population of Sub-Saharan Africa. For these countries irrigation is likely to be an essential part of any overall national strategy for increased agricultural production. Twelve countries (Botswana, Burkina Faso, Chad, Ethiopia, Kenya, Mali, Mauritania, Niger, Somalia, Sudan, Tanzania, and Zimbabwe) have a rainfed growing period of less than 120 days on over a quarter of their territory, and another 10 countries have up to a quarter of their area in the same semi-arid zone. In the semi-arid regions of these countries, irrigation is usually necessary for reliable crop production (FAO 1986).

IRRIGATED CROP AREA AND YIELD

The crops grown under irrigation vary widely across the continent, but data are incomplete and do not permit a complete assessment of the area planted to each crop on a country-by-country basis. FAO (1995a) synthesized a wide range of materials and compiled an estimate of the distribution of crops grown on nearly three-fourths of the physical area with water control. In Africa as a whole, rice accounts for nearly one-third of water managed area,[1] and other cereals for just over one-third of the area, with much of this in wheat in North Africa. The remaining one-third is distributed among vegetables, fodder, industrial crops, and arboriculture. Rice is the main crop in the humid zones in Western and Eastern Africa, and in Madagascar, but is relatively unimportant in the Northern and Southern regions. Other cereals are mainly irrigated in the North and Sudano-Sahelian regions, but also have a strong

[1] FAO differentiates between irrigated area (water managed area equipped with hydraulic structures) and water managed area (irrigated areas and cultivated wetlands and valley bottoms without irrigation equipment and recession cropping areas).

concentration in the Southern region. Irrigated vegetables, and roots and tubers are present throughout the continent, but concentrated in Eastern Africa (Table 6).

Irrigated crop yields in Sub-Saharan Africa are generally lower than in other regions of the world (Table 7). However, the percentage difference between irrigated and rainfed crop yields within Africa is comparable to other regions.

Table 8 shows trends in irrigated area in Africa by region. There has been faster growth in North Africa in the past decade, due mainly to new areas in Egypt. In Sub-Saharan Africa, growth in irrigated area has slowed since the early 1980s due to the lagged effects of declining irrigation investment beginning in the late 1970s.

5. STRATEGIES FOR THE FUTURE

The challenges posed by growing water scarcity can be addressed through two strategies: supply management, which involves activities to locate, develop, and exploit new sources of water for irrigation, household, and industrial uses; and demand management, which addresses the incentives and mechanisms that promote water conservation and efficient water use. The distinction between these 2 modes of management is not clear-cut: is investment in lining an irrigation canal to reduce water losses supply management or demand management? A useful working definition is that actions and policies that affect the quantity and quality of water at the entry point into the distribution system are classified as supply management, and actions that influence the use or wastage of water after this point as demand management (UNDTC 1991; World Bank 1994).

Table 6 Regional distribution of main irrigated crops (partial information)

Region	Rice	Other Cereals	Vegetables, Roots and Tubers	Fodder	Industrial Crops	Arboriculture	Total
				(thousand hectares)			
Northern	538 (11%)	2,221 (45%)	423 (9%)	1,207 (24%)	80 (2%)	459 (9%)	4,928 (100%)
Sudano-Sahelian	384 (22%)	839 (48%)	61 (3%)	4 (-)	471 (27%)	1 (-)	1,760 (100%)
Western	993 (80%)	52 (4%)	168 (14%)	- (-)	21 (2%)	6 (-)	1,240 (100%)
Central	21 (29%)	- (-)	4 (6%)	- (-)	42 (59%)	4 (6%)	71 (100%)
Eastern	173 (38%)	80 (18%)	158 (35%)	- (-)	33 (7%)	8 (2%)	452 (100%)
Islands (I.O.)	880 (97%)	- (-)	- (-)	- (-)	31 (3%)	- (-)	911 (100%)
Southern	147 (13%)	358 (32%)	42 (4%)	353 (31%)	198 (17%)	32 (3%)	1,130 (100%)
Total	3,136 (30%)	3,550 (34%)	856 (8%)	1,564 (15%)	876 (8%)	510 (5%)	10,492 (100%)

Source: FAO 1995a.

Table 7 Average yields on rainfed and irrigated land, selected food crops

	Wheat	Rice	Maize	Barley	Millet	Sorghum	Pulses	Vegetables
				(tons per hectare)				
Developing countries								
Rainfed	1.5	2.1	1.5	1.2	0.6	0.8	0.5	5.4
Irrigated	2.4	3.7	3.7	1.8	1.9	2.8	1.1	13.0
Sub-Saharan Africa								
Rainfed	1.3	1.4	1.2	1.0	0.7	0.7	0.5	3.7
Irrigated	2.1	2.7	3.1	5.3	1.8	2.1	1.1	5.3
Latin America & Caribbean								
Rainfed	1.8	1.6	1.7	1.6	1.5	2.4	0.5	9.1
Irrigated	4.1	4.4	3.9	1.8	-	4.8	1.2	15.9
South Asia								
Rainfed	1.0	2.2	1.3	0.7	0.5	0.6	0.5	5.2
Irrigated	2.3	3.1	2.2	1.9	1.9	2.3	1.0	10.6
East Asia[1]								
Rainfed	1.2	2.0	1.8	2.7	0.8	1.3	0.8	5.1
Irrigated	2.2	4.3	5.7	3.5	-	-	1.3	14.23
Near East/North Africa								
Rainfed	1.4	-	2.0	1.1	0.6	0.9	0.8	9.4
Irrigated	2.4	4.3	4.3	1.8	0.8	3.3	1.4	17.0

Source: FAO 1995c.

[1] Excludes China.

Table 8 Irrigated area in Africa, 1970-1993

Year	North Africa	Africa	Sub-Saharan Africa Total	Central and West	East	North	South
1970	9,034	4,376	4,658	1,020	80	1,993	1,565
1975	9,557	4,529	5,028	1,061	105	2,080	1,782
1980	10,110	4,383	5,727	1,126	180	2,233	2,188
1981	10,255	4,439	5,816	1,139	180	2,259	2,238
1982	10,362	4,468	5,894	1,149	184	2,273	2,288
1983	10,533	4,600	5,933	1,161	186	2,273	2,313
1984	10,831	4,631	6,200	1,195	188	2,469	2,348
1985	10,942	4,680	6,262	1,206	196	2,449	2,411
1986	11,232	4,754	6,478	1,261	215	2,456	2,546
1987	11,347	4,803	6,544	1,263	217	2,470	2,594
1988	11,504	4,841	6,663	1,267	220	2,482	2,694
1989	11,678	4,871	6,807	1,269	223	2,513	2,802
1990	11,901	5,060	6,841	1,275	225	2,515	2,826
1991	12,053	5,178	6,875	1,310	231	2,515	2,819
1992	12,320	5,313	7,007	1,317	237	2,518	2,935
1993	12,970	5,914	7,056	1,324	243	2,571	2,918
Growth rates (%)							
1970-82	1.12	-0.08	2.13	1.04	7.67	1.21	3.41
1982-93	1.81	2.04	1.62	1.20	2.61	0.76	2.55

Source: FAO 1995d.

Note: IMPACT distinguishes between Sub-Saharan Africa, including -

CENTRAL AND WESTERN SUB-SAHARAN AFRICA (SSA): Benin, Cameroon, Central African Republic, Comoros, Congo, Côte d'Ivoire, Gabon, Gambia, Ghana, guinea, Guinea-Bissau, Liberia, Nigeria, São Tome and Principe, Senegal, Sierra Leone, Togo, and Zaire.

EASTERN SSA: Burundi, Kenya, Rwanda, Tanzania, and Uganda.

NORTHERN SSA: Burkina-Faso, Chad, Djibouti, Ethiopia, Sudan, Mali, Mauritania, Niger, and Somalia.

SOUTHERN SSA: Angola, Botswana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Reunion, South Africa (only for this study), Swaziland, Zambia, Zimbabwe,

and West Asia and North Africa (WANA), including -

NORTH AFRICA: Algeria, Egypt, Libya, Morocco, Tunisia, and Western Sahara.

WEST ASIA: Bahrain, Cyprus, Gaza Strip, Iran, Irak, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, and Yemen.

The evidence suggests that meeting the challenges of water scarcity will require both more vigorous demand management, with comprehensive water policy reform to make better use of existing supplies; and supply management involving highly selective development and exploitation of new water supplies. The appropriate mix of supply and demand management will vary with levels of development and water scarcity. At their present stages of economic and water resources development, most of Sub-Saharan Africa will likely be primarily concerned with supply augmentation, but should begin planning for improved demand management, while North Africa should be moving aggressively into demand management measures and strategies.

As economies grow and competition for water and the value of water increase, the benefits from, and necessity for, demand management increase significantly. Randall (1981) argues that as "water economies" move from the expansionary phase to the mature phase, conditions for the establishment of property rights emerge: the long-run supply of impounded or diverted water becomes inelastic; the demand for delivered water increases rapidly; competition for water among agricultural, industrial, urban, and instream uses increases; and externality problems, including rising water tables, land salinization, and groundwater salinization and depletion become increasingly important. All of these factors increase the value of water and therefore the benefits from efficient allocation of water; and they shift the likely balance of effort from supply management to demand management.

In the remainder of the paper we examine water supply augmentation and demand management options for Africa.

6. SUPPLY AUGMENTATION: INVESTMENT IN IRRIGATION AND WATER DEVELOPMENT

As shown above, expansion of irrigated area has slowed in most of Sub-Saharan Africa, while demand for food and water continues to grow rapidly. What is the potential for investment in new irrigation systems and development of new water supplies? Although we will not see a return to earlier rapid rates of growth in irrigated area, some of the needed growth in food production must come from expansion of irrigated area, and a portion of the incremental demand for water must be met from carefully selected, economically efficient development of new water, both through impoundment of surface water and sustainable exploitation of groundwater resources, and, particularly in North Africa, through expansion in the development of non-traditional water sources.

7. IMPACT OF IRRIGATION INVESTMENT IN AFRICA: PROJECTIONS TO 2020

INTRODUCTION

This section explores the impact of increased irrigation investment in Africa on supply, demand, trade, world prices of major food commodities, and food security to the year 2020 with the use of IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). IMPACT provides a consistent framework to test the effects of policies, different rates of crop productivity growth, and income and population growth on long-term demand and supply. IMPACT covers 35 countries and regions (which account for virtually all of world food production and consumption), and 17 commodities, including all cereals, roots and tubers, meats, and dairy products.

The model is specified as a set of country-level supply and demand equations. Each country model is linked to the rest of the world through trade. World commodity prices are determined as the prices which clear all global commodity markets. Growth in crop production in each country is determined by crop prices and the rate of productivity growth due to agricultural research, irrigation, and other investments. Demand is a function of prices, income and population growth.

In order to explore food security effects, the number of malnourished pre-school children in developing countries is projected as a function of per capita calorie availability, social expenditures, female education, and access to clean water. For a detailed description of IMPACT, see Rosegrant, Agcaoili-Sombilla, and Perez (1995).

Baseline simulations of IMPACT project a rapid growth in food imports, particularly cereals, in Sub-Saharan Africa and North Africa and West Asia (WANA) (note that IMPACT does not allow separation of North Africa and West Asia). Cereal imports are projected to increase dramatically, from 9.2 million metric tons in 1990 to 29 million metric tons in 2020 for Sub-Saharan Africa, and from 41.7 million metric tons to 67.7 million metric tons for WANA (Table 9).

To bridge this projected import gap in Africa, very rapid production increases would be required from technology improvement through agricultural research and land development through investment in irrigation. This paper focuses on irrigation investment as a way of increasing land productivity and helping close the projected import gap for Africa. A scenario of high investment in irrigation for Africa is simulated using IMPACT.

HIGH IRRIGATION INVESTMENT SCENARIO

Under the baseline scenario, which is based on recent trends in irrigation expansion, irrigated land area is projected to increase from 11.9 million hectares to 15.9 million hectares between 1990 and 2020, an increase of 33 percent in 30 years (Table 10). North Africa's irrigated land area is projected to increase by 31 percent, and irrigated area in Sub-Saharan Africa is expected to increase by 35 percent. The highest percentage increase is projected for Eastern Sub-Saharan Africa, where irrigated land area is projected to more than double, from 0.23 million hectares in 1990 to 0.49 million hectares in 2020.

The high irrigation investment scenario assumes more aggressive investment in irrigation. Under this scenario, irrigated land area for Africa would expand from 11.9 million hectares in 1990 to 22.8 million hectares in 2020, a 92 percent increase in 30 years, and a 44 percent increase over the baseline projections of 15.8 million hectares. North Africa is projected to develop an additional 0.7 million hectares of land (11 percent over the baseline), and Sub-Saharan Africa is expected to have an additional 6.2 million hectares of irrigated land compared to the baseline (67 percent over the baseline figures). Nigeria and Central and Western Sub-Saharan Africa would have more than twice the irrigated land area

Table 9 Cereals: Baseline projections for Africa

	1990			2020		
Commodity/Sub-region	Production	Demand	Net Trade	Production	Demand	Net Trade
WHEAT						
Sub-Saharan Africa (SSA)						
Nigeria	78	279	-201	204	664	-460
Northern SSA	1,089	2,863	-1,774	2,803	7,029	-4,226
Central and Western SSA	197	1,552	-1,355	744	4,045	-3,301
Southern SSA	219	1,627	-1,408	431	3,926	-3,495
Eastern SSA	135	548	-413	339	1,677	-1,338
SSA Total:	*1,718*	*6,869*	*-5,151*	*4,521*	*17,341*	*-12,820*
West Asia and North Africa	45,314	72,146	-26,832	101,458	142,593	-41,135
SSA and WANA Total:	*47,032*	*79,015*	*-31,983*	*105,979*	*159,934*	*-53,955*
MAIZE						
Sub-Saharan Africa (SSA)						
Nigeria	2,015	2,015	0	5,188	4,763	425
Northern SSA	3,001	3,001	0	7,120	7,328	-208
Central and Western SSA	3,454	3,519	-65	9,393	9,152	241
Southern SSA	6,403	6,658	-255	14,625	15,403	-778
Eastern SSA	6,195	6,115	80	14,830	17,252	-2,422
SSA Total:	*21,068*	*21,308*	*-240*	*51,156*	*53,898*	*-2,742*
West Asia and North Africa	8,145	13,939	-5,794	15,357	24,201	-8,844
SSA and WANA Total:	*29,213*	*35,247*	*-6,034*	*66,513*	*78,099*	*-11,586*
RICE						
Sub-Saharan Africa (SSA)						
Nigeria	388	530	-142	765	1,786	-1,021
Northern SSA	427	875	-448	1,101	2,322	-1,221
Central and Western SSA	1,882	2,970	-1,088	5,655	7,739	-2,084
Southern SSA	1,339	2,164	-825	3,491	5,258	-1,767
Eastern SSA	245	543	-298	584	1,601	-1,017
SSA Total:	*4,281*	*7,082*	*-2,801*	*11,596*	*18,706*	*-7,110*
West Asia and North Africa	3,549	5,869	-2,320	6,655	11,611	-4,956
SSA and WANA Total:	*7,830*	*12,951*	*-5,121*	*18,251*	*30,317*	*-12,066*
OTHER GRAINS						
Sub-Saharan Africa (SSA)						
Nigeria	8,887	8,948	-61	21,792	21,522	270
Northern SSA	13,275	13,506	-231	30,691	33,815	-3,124
Central and Western SSA	2,416	2,858	-442	1,752	2,875	-1,123
Eastern SSA	2,109	2,122	-13	4,897	6,194	-1,297
SSA Total:	*27,513*	*28,603*	*-1,090*	*65,559*	*71,977*	*-6,418*

Table 9 (continued)

Commodity/Sub-region	1990 Production	1990 Demand	1990 Net Trade	2020 Production	2020 Demand	2020 Net Trade
West Asia and North Africa	19,465	26,260	-6,795	34,475	47,259	-12,784
SSA and WANA Total:	*46,978*	*54,863*	*-7,885*	*100,034*	*119,236*	*-19,202*
ALL CEREALS						
Sub-Saharan Africa (SSA)						
Nigeria	11,368	11,772	-404	27,949	28,735	-786
Northern SSA	17,792	20,245	-2,453	41,715	50,494	-8,779
Central and Western SSA	7,949	10,899	-2,950	22,219	28,507	-6,288
Southern SSA	8,787	11,618	-2,831	20,299	27,462	-7,163
Eastern SSA	8,684	9,328	-644	20,650	26,724	-6,074
SSA Total:	*54,580*	*63,862*	*-9,282*	*132,832*	*161,922*	*-29,090*
West Asia and North Africa	76,473	118,214	-41,741	157,945	225,664	-67,719
SSA and WANA Total:	*131,053*	*182,076*	*-51,023*	*290,777*	*387,586*	*-96,809*

Source: IMPACT simulations.

Table 10 Projected irrigated area, Africa, under alternative scenarios

Region	1990	2020 Baseline	2020 High irrigation investment
		(000 ha)	
Africa	11,901	15,862	22,798
North Africa	5,060	6,620	7,320
Sub-Saharan Africa	6,841	9,242	15,478
Northern SSA	2,515	3,156	4,830
Central and Western SSA	1,275	1,823	4,076
Eastern SSA	225	487	972
Southern SSA	2,826	3,776	5,600

Source: IMPACT simulations.

in 2020 under this scenario than under the baseline assumptions (2.9 and 1.2 million hectares against 1.3 million and 0.5 million hectares, respectively), Eastern Sub-Saharan Africa would have almost twice as much (0.97 million hectares against 0.49 million hectares), while the Northern and Southern Sub-Saharan African regions are projected to have increases of around 50 percent (respectively, 4.8 against 3.1 million hectares and 5.6 against 3.8 million hectares) over the baseline projections.

PROJECTED IMPACT OF INCREASED IRRIGATION INVESTMENT

To measure the impact of increased irrigation investment in Africa, results of simulations for the high irrigation investment scenario are compared with the baseline simulation results. Area, production, demand, and trade comparisons are presented in Table 11, world price changes are in Table 12, and nutrition effects in Table 13.

Area and Production

Cereals (rice, wheat, maize, and other grains) are the major commodities whose area and production are directly influenced by increased investment in irrigation. Although irrigated land area is projected to increase by 44 percent under the high irrigation investment scenario, compared to the baseline scenario (Table 10), its net effect on total cereal area in 2020 for all African regions (Sub-Saharan Africa, West Asia and North Africa - WANA) is a projected increase to 145 million hectares, a 4.1 percent increase from the baseline projected value of 139 million hectares. Under this case, cereal production is projected to increase by 6.9 percent (from 291 to 311 million metric tons), compared to the baseline results (Table 11).

For Sub-Saharan Africa, the 67 percent incremental increase in irrigated area will be translated into a 5.8 percent incremental increase in cereal area and an 11.8 percent increase in cereal production, while for WANA, the 10.6 percent increase in irrigated area in North Africa will be translated into a 1.5 percent increase in cereal area and a 2.7 percent increase in cereal production. Among the Sub-Saharan regions, the Central/Western and Southern regions have the highest incremental increase in both cereal area and production

Table 11 Changes in cereal area, production, demand, and trade in 2020 due to increased investment in irrigation in Africa

	Baseline				High Irrigation Investment				Change from Baseline			
Commodity/ Sub-region	Area	Production	Demand	Net Trade	Area	Production	Demand	Net Trade	Area	Production	Demand	Net Trade
										(percent)		*(difference)*
WHEAT												
Sub-Saharan Africa (SSA)												
Nigeria	96	204	664	-460	102	231	667	-436	6.25	13.24	0.45	24
Northern SSA	1,014	2,803	7,029	-4,226	1,067	3,116	7,057	-3,941	5.23	11.17	0.40	285
Central and Western SSA	271	744	4,045	-3,301	291	848	4,061	-3,213	7.38	13.98	0.40	88
Southern SSA	198	431	3,926	-3,495	213	493	3,942	-3,449	7.58	14.39	0.41	46
Eastern SSA	141	339	1,677	-1,338	147	370	1,686	-1,316	4.26	9.14	0.54	22
SSA Total:	*1,720*	*4,521*	*17,341*	*-12,820*	*1,820*	*5,058*	*17,413*	*-12,355*	*5.81*	*11.88*	*0.42*	*465*
West Asia and North Africa	32,387	101,458	142,593	-41,135	32,932	104,567	143,155	-38,588	1.68	3.06	0.39	2,547
SSA and WANA Total:	*34,107*	*105,979*	*159,934*	*-53,955*	*34,752*	*109,625*	*160,568*	*-50,943*	*1.89*	*3.44*	*0.40*	*3,012*
MAIZE												
Sub-Saharan Africa (SSA)												
Nigeria	2,540	5,188	4,763	425	2,711	5,866	4,782	1,084	6.73	13.07	0.40	659
Northern SSA	3,812	7,120	7,328	-208	4,001	7,870	7,356	514	4.96	10.53	0.38	722
Central and Western SSA	6,021	9,393	9,152	241	6,449	10,659	9,189	1,470	7.11	13.48	0.40	1,229
Southern SSA	8,082	14,625	15,403	-778	8,660	16,601	15,465	1,136	7.15	13.51	0.40	1,914
Eastern SSA	5,332	14,830	17,252	-2,422	5,563	16,104	17,320	-1,216	4.33	8.59	0.39	1,206
SSA Total:	*25,787*	*51,156*	*53,898*	*-2,742*	*27,384*	*57,100*	*54,112*	*2,988*	*6.19*	*11.62*	*0.40*	*5,730*
West Asia and North Africa	2,466	15,357	24,201	-8,844	2,501	15,755	24,315	-8,560	1.42	2.59	0.47	284
SSA and WANA Total:	*28,253*	*66,513*	*78,099*	*-11,586*	*29,885*	*72,855*	*78,427*	*-5,572*	*5.78*	*9.53*	*0.42*	*6,014*
RICE												
Sub-Saharan Africa (SSA)												
Nigeria	624	765	1,786	-1,021	666	891	1,788	-897	6.73	16.47	0.11	124
Northern SSA	674	1,101	2,322	-1,221	709	1,248	2,325	-1,077	5.19	13.35	0.13	144
Central and Western SSA	3,820	5,655	7,739	-2,084	4,100	6,613	7,748	-1,135	7.33	16.94	0.12	949
Southern SSA	1,925	3,491	5,258	-1,767	2,067	4,084	5,265	-1,181	7.38	16.99	0.13	586

Table 11 (continued)

Commodity/ Sub-region	Baseline Area	Baseline Production	Baseline Demand	Baseline Net Trade	High Irrigation Investment Area	High Irrigation Investment Production	High Irrigation Investment Demand	High Irrigation Investment Net Trade	Change from Baseline Area	Change from Baseline Production	Change from Baseline Demand	Change from Baseline Net Trade
										(percent)		*(difference)*
Eastern SSA	556	584	1,601	-1,017	581	654	1,603	-949	4.50	11.99	0.12	68
SSA Total:	*7,599*	*11,596*	*18,706*	*-7,110*	*8,123*	*13,490*	*18,729*	*-5,239*	*6.90*	*16.33*	*0.12*	*1,871*
West Asia and North Africa	1,300	6,655	11,611	-4,956	1,321	6,912	11,626	-4,714	1.62	3.86	0.13	242
SSA and WANA Total:	*8,899*	*18,251*	*30,317*	*-12,066*	*9,444*	*20,402*	*30,355*	*-9,953*	*6.12*	*11.79*	*0.13*	*2,113*
OTHER GRAINS												
Sub-Saharan Africa (SSA)												
Nigeria	12,466	21,792	21,522	270	13,240	24,489	21,662	2,827	6.21	12.38	0.65	2,557
Northern SSA	24,426	30,691	33,815	-3,124	25,592	33,816	34,108	-292	4.77	10.18	0.87	2,832
Central and Western SSA	5,022	6,427	7,571	-1,144	5,370	7,270	7,637	-367	6.93	13.12	0.87	777
Southern SSA	1,712	1,752	2,875	-1,123	1,831	1,983	2,900	-917	6.95	13.18	0.87	206
Eastern SSA	4,357	4,897	6,194	-1,297	4,537	5,302	6,247	-945	4.13	8.27	0.86	352
SSA Total:	*47,983*	*65,559*	*71,977*	*-6,418*	*50,570*	*72,860*	*72,554*	*306*	*5.39*	*11.14*	*0.80*	*6,724*
West Asia and North Africa	20,101	34,475	47,259	-12,784	20,361	35,037	47,753	-12,716	1.29	1.63	1.05	68
SSA and WANA Total:	*68,084*	*100,034*	*119,236*	*-19,202*	*70,931*	*107,897*	*120,307*	*-12,410*	*4.18*	*7.86*	*0.90*	*6,792*
ALL CEREALS												
Sub-Saharan Africa (SSA)												
Nigeria	15,726	27,949	28,735	-786	16,719	31,477	28,899	2,578	6.31	12.62	0.57	3,364
Northern SSA	29,926	41,715	50,494	-8,779	31,369	46,050	50,846	-4,796	4.82	10.39	0.70	3,983
Central and Western SSA	15,134	22,219	28,507	-6,288	16,210	25,390	28,635	-3,245	7.11	14.27	0.45	3,043
Southern SSA	11,917	20,299	27,462	-7,163	12,771	23,161	27,572	-4,411	7.17	14.10	0.40	2,752
Eastern SSA	10,386	20,650	26,724	-6,074	10,828	22,430	26,856	-4,426	4.26	8.62	0.49	1,648
SSA Total:	*83,089*	*132,832*	*161,922*	*-29,090*	*87,897*	*148,508*	*162,808*	*-14,300*	*5.79*	*11.80*	*0.55*	*14,790*
West Asia and North Africa	56,254	157945	225,664	-67,719	57,115	162,271	226,849	-64,578	1.53	2.74	0.53	3,141
SSA and WANA Total:	*139,343*	*290,777*	*387,586*	*-96,809*	*145,012*	*310,779*	*389,657*	*-78,878*	*4.07*	*6.88*	*0.53*	*17,931*

Source: IMPACT simulations.

Table 12 Change in world prices of commodities in 2020, high investment in irrigation in Africa scenario

Commodity	Baseline	High irrigation investment	Percent change
	$/mt		*%*
Wheat	133	131	-1.50
Maize	85	82	-3.53
Rice	185	183	-1.08
Other grains	67	65	-2.99
Soybeans	223	222	-0.45
Roots and tubers	122	121	-0.82
Beef	1,959	1,955	-0.20
Pigmeat	1,505	1,501	-0.27
Sheepmeat	1,835	1,830	-0.27
Poultry meat	664	662	-0.30
Eggs	670	668	-0.30

Source: IMPACT simulations.

Table 13 Change in food availability and number of malnourished children in 2020, high investment in irrigation in Africa scenario

	Food availability			
	1990	2020		
Region		Baseline	High irrigation investment	Percent change
		(kcal/cap/day)		*(%)*
Sub-Saharan Africa (SSA)				
Nigeria	2,073	2,273	2,279	0.26
Northern SSA	1,898	1,964	1,975	0.56
Central and Western SSA	2,183	2,268	2,273	0.22
Southern SSA	2,025	2,152	2,157	0.23
Eastern SSA	2,092	2,320	2,326	0.26
SSA Total:	*2,053*	*2,189*	*2,195*	*0.27*
West Asia and North Africa	2,988	3,110	3,118	0.26
SSA and WANA Total:	*2,416*	*2,504*	*2,511*	*0.28*

	Percent malnourished children			
	1990	2020		
Region		Baseline	High irrigation investment	Percent change
	%	*%*		
Sub-Saharan Africa (SSA)				
Nigeria	35.40	29.30	29.16	-0.14
Northern SSA	31.40	27.75	27.49	-0.26
Central and Western SSA	22.70	20.01	19.95	-0.06
Southern SSA	24.80	20.88	20.79	-0.09
Eastern SSA	25.50	21.66	21.55	-0.11
SSA Total:	*28.39*	*24.31*	*24.17*	*-0.14*
West Asia and North Africa	13.40	9.73	9.68	-0.05
SSA and WANA Total:	*22.56*	*19.32*	*19.21*	*-0.11*

	Number of malnourished children			
	1990	2020		
Region		Baseline	High irrigation investment	Percent change
		(million)		
Sub-Saharan Africa (SSA)				
Nigeria	8.01	10.81	10.76	-0.05
Northern SSA	7.40	10.45	10.35	-0.10
Central and Western SSA	5.28	7.95	7.93	-0.02
Southern SSA	3.59	4.99	4.96	-0.02
Eastern SSA	4.34	6.82	6.79	-0.03
SSA Total:	*28.61*	*41.02*	*40.79*	*-0.23*
West Asia and North Africa	6.76	6.32	6.28	-0.04
SSA and WANA Total:	*35.37*	*47.34*	*47.08*	*-0.26*

Source: IMPACT simulations.

(respectively, around 7 percent and 14 percent), followed by Nigeria with 6.3 percent in area and 12.6 percent in production.

The greatest incremental increases are realized for rice and maize, whose total area is projected to increase by 6.1 percent and 5.8 percent, and production by 11.8 percent and 9.5 percent, respectively, from the baseline results. The highest incremental increases in area and production are in the Southern (7.4 percent in rice and 7.2 percent in maize area, and 17.0 percent in rice and 13.5 percent in maize production) and Central and Western Sub-Saharan regions (7.3 percent in rice and 7.1 percent in maize area, and 16.9 percent in rice and 13.5 percent in maize production).

Prices, Demand, and Net Trade

Under the high irrigation investment scenario, world prices of commodities in 2020 are expected to decline very slightly, due to projected increases in cereal production in Africa (Table 12). Cereal prices are projected to decline in the range of 1.2 percent for rice to 3.5 percent for maize, and meat products prices are expected to decline, on average, by 0.3 percent from baseline values.

High investment in irrigation has also little effect on cereal demand (Table 11). Total cereal demand is projected to increase only by 0.53 percent from baseline values for all African regions (0.55 percent for Sub-Saharan Africa and 0.53 percent for WANA). The relatively lower increases in cereal demand as compared to cereal production (11.8 percent for Sub-Saharan Africa and 2.7 percent for WANA)will result in declining cereal imports for the regions. Cereal imports are projected to decrease from 96.8 million metric tons (29.1 million metric tons for Sub-Saharan Africa and 67.7 million metric tons for WANA) under the baseline scenario to 78.9 million metric tons (14.3 million metric tons for Sub-Saharan Africa and 64.6 million metric tons for WANA); this is equivalent to a 18.5 percent (50.1 percent for Sub-Saharan Africa and 4.6 percent for WANA) cereal import reduction.

Changes in net trade due to high irrigation investments are distributed as follows. Net trade of cereals in Nigeria is projected to change from 0.8 million metric tons of imports to 2.6 million metric tons of cereal exports - a positive gain in the trade balance of 3.4 million metric tons. Northern Sub-Saharan Africa total cereals imports decline by 45 percent, from 8.8 million metric tons to 4.8 million metric tons. Central and Western Sub-Saharan Africa cereal imports decrease by 48 percent, Southern Sub-Saharan Africa imports by 38 percent, and Eastern Sub-Saharan Africa imports by 27 percent. These positive gains in net trade are due mainly to declines in wheat and rice imports, and increases in maize exports (Nigeria and Central and Western Sub-Saharan Africa) and shifts from being maize net importers to net exporters (Northern and Southern Sub-Saharan Africa).

Child Malnutrition

Table 13 presents the changes in average per capita calorie availability per day, projected percentage of malnourished children, and projected number of malnourished children in Africa (and West Asia). The baseline projection depicts a deterioration in food security, with a projected rise in the absolute number of malnourished children in Sub-Saharan Africa from 28.6 million in 1990 to 41.0 million in 2020. Even with high irrigation investment in Africa, projected improvements in per capita food availability will not be adequate to substantially reduce malnutrition in the region. Without additional income growth and increases in social expenditures for health and education, only a slight improvement in the nutrition situation (around 0.25 million less malnourished children) is projected from the high irrigation investment strategy.

Results

These results indicate that increased irrigation investment in Africa can make a significant, though not transforming, impact on food production growth. The amount of land under irrigation, and the potential area exploitable relative to total crop area is simply not large enough to generate revolutionary changes in crop production. However, the impacts that are generated from investment in irrigation are important. Probably the most significant impact is the reduction in cereal imports in Sub-Saharan Africa from 29 million metric tons to 14 million metric tons in 2020.

These savings of imports alone could justify the added irrigation investment, subject to the cost-effectiveness of individual investment projects. The high investment scenario generates 7 million hectares of additional irrigated crop area by 2020 compared to the baseline projected area. Assuming that one-half of the expansion was from full-control medium to large irrigation systems with costs of US$8,300 per hectare (see below) and one-half was from a mix of small-scale and very small farmer-controlled systems with an average cost of US$5,000 per hectare, the total investment cost through the year 2020 to generate this acreage would be US$46.55 billion. By comparison, the accumulated value of cereal imports saved during 1995-2020 (evaluated at projected real world prices over the period) through the high irrigation investment strategy would be US$52.5 billion. Thus, well before the end of their effective lifetime, the portfolio of irrigation projects under the high investment strategy would generate savings on cereal import costs which are greater than the total investment costs.

8. FUTURE IRRIGATION INVESTMENT STRATEGIES: LESSONS FROM EXPERIENCE

INTRODUCTION

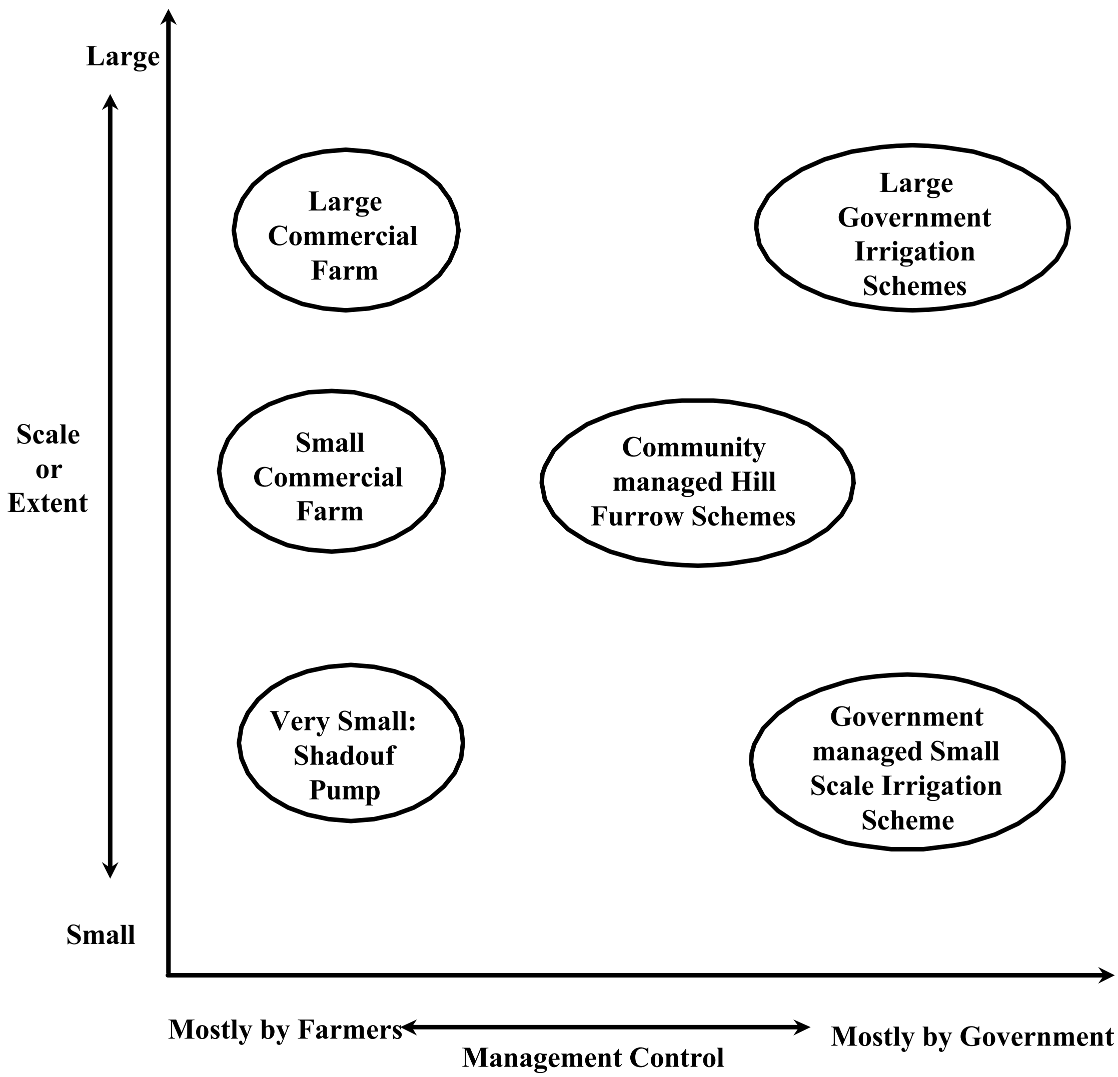
The question of future investment strategies for African irrigation is often posed as one of scale. The spectacular failures of some large-scale systems have been used to advocate future investment strategies based on small-scale irrigation systems. However, a more careful understanding indicates failures and successes in both large-scale and small-scale systems, and suggests that scale *per se* is less important in determining success than the extent to which control is operated by the farmers and, where systems are managed bureaucratically, the quality of management and equitable distribution of income to farmers within the project (Underhill 1990; Adams 1990; Brown and Nooter 1992). The following sections on the development of surface irrigation systems focus primarily on Sub-Saharan Africa, as the physical potential for further development of surface irrigation is limited in North Africa.

Adams (1990) provides a useful continuum of irrigation systems, which is reproduced in Figure 1. At one end of the continuum are the very small-scale systems managed by individual farmers *(shadouf, dambos, fadamas*), and at the other extreme (of both dimensions) are large, government-run irrigation systems. However, farmer-managed schemes also encompass small and large commercial farms, while governments also construct and operate small-scale irrigation schemes. Community-managed schemes are intermediate on the continuum.

LARGE-SCALE IRRIGATION

Horror stories about large-scale irrigation in Africa abound, with per hectare construction costs as high as US$40,000 per hectare, and estimated negative rates of return. The most prevalent sources of failure are design and technical flaws, management failures, and political difficulties. Together, these failures have led to far higher than expected costs and lower than expected benefits. The least effective (and most expensive) of these failed systems experienced severe technical problems during design and construction phases. In many instances, the initial design work was faulty or incomplete, requiring mid-term corrections and rebuilding of schemes, leading to drastic cost inflation (Moris and Thom 1990). In some cases, the likelihood of poor performance was clear at the appraisal stage, but the projects went forward, primarily for political reasons (Lele and Subramanian 1990; Adams 1990). The Bura system in Kenya, built between 1977 and 1984, is a classic example of a failed large-scale project. At the initial appraisal stage, irrigation was planned for 6,000 hectares, and estimated costs were US$98 million. However, additional appraisals identified soil problems, including salinity, high sodium content, and low subsoil permeability, that resulted in a reduction of the area to be irrigated to 3,900 hectares. At the same time, costs escalated to US$128 million, a cost per hectare of US$32,000 and negative rates of return to the investment (Lele and Subramanian 1990; Adams 1990; Moris and Thom 1990).

Figure 1 Relations between scale and form of control in irrigation



Source: Adams 1990.

Management problems have also contributed to the failure of many large-scale schemes. Office du Niger irrigation schemes in Mali have performed very poorly and produced low returns. This parastatal corporation was financially independent due to income from farmers' fees, but utilized only 20 percent of fee income on purchases of farm inputs, with the remainder being put back into central operations. By 1983, there was one staff member for every 1.5 farmers and 11 hectares of irrigation (Brown and Nooter 1992). This pattern of excessive centralization of management has often been repeated in African irrigation. The inability of ministry and agency headquarters to respond in a timely and efficient manner to field-level problems leads to poor performance and returns. Excessive centralization takes control from the hands of farmers and perimeter directors without providing a viable substitute. Other problems encountered by centralized bureaucratic management in government irrigation systems include poor training and skill levels, uncontrolled overhead costs, and rent-seeking.

However, it is important to note that other large-scale irrigation systems have been successful. Semry I and II in Cameroon have had estimated rates of return above 20 percent under highly centralized management regimes. Management of water, agronomic decisions, and cost recovery were handled by project management rather than farmers and (unlike in the Office du Niger) high financial returns were maintained for the farmers, ensuring their continued participation and support. Brown and Nooter (1992) name efficient management, relatively low-cost infrastructure, low operating costs, good technical design, which was fully operational at project completion, and availability of agronomically suitable crops and cropping systems as conditions for success of Semry I and II.

How can enough of these conditions be met to generate sufficient returns to justify investment in large-scale irrigation? More general evidence suggests that investment costs in Sub-Saharan Africa are higher than in other parts of the world, but not as high as suggested by the prominently disastrous projects; that there are high risks of failure from investment in large systems; but that with careful selection and improved management the examples of relatively successful large-scale irrigation schemes can be replicated.

The estimated average cost for new full-control medium- to large-scale irrigation in Sub-Saharan Africa is US$8,300 per hectare in 1995 dollars, compared to US$6,800 in North Africa and US$2,500 in South Asia (FAO 1995b). The costs of small-scale irrigation with full water control in Sub-Saharan Africa are about US$4,000-$5,000 per hectare, excluding farmer contributions to labor and survey costs. With full costing, full-control small-scale irrigation may cost as much or more than large-scale irrigation (FAO 1995b). Construction cost estimates from the World Bank, based on the analysis of "all possible projects" within each of several countries in Sub-Saharan Africa, are somewhat lower than the FAO estimates. The weighted average of irrigation costs across projects was US$5,900 per hectare in Botswana; US$5,600 per hectare in Kenya; US$2,850 per hectare in Sudan; US$2,000 per hectare in Zambia; US$9,500 per hectare in Zimbabwe (in 1984 US dollars for Sudan, and in 1985 US dollars for the rest). (Olivares 1990)

Both the World Bank and FAO estimates cited above include only the direct cost for irrigation. A recent review of World Bank irrigation investments estimated that costs average US$18,300 per hectare when indirect costs for social infrastructure, including roads, houses, electric grids, and public service facilities, are included (Jones 1995). However, even the direct costs are higher than in Asia, due to physical and external constraints. FAO (1986, 1987) provides a comprehensive summary of the reasons for higher direct irrigation investment costs: physical/hydrological conditions are difficult, with reservoirs and dams needed to stabilize the erratic flows of many African rivers. Due to the predominantly flat local topography, suitable dam locations are usually located along the escarpment, requiring long canals to bring the water to the irrigated flat lands. In North Africa, dam locations are easier to find but the quantities of water mobilized are low in relation to cost due to lower rainfall. Flood protection dykes are necessary for most rice irrigation. In many Asian countries, such dikes were built long ago and no longer appear as investment costs, whereas they often account for one-quarter of the cost of civil works in West Africa. The patchy distribution of irrigable soils and the uneven shape and topography of many African irrigation sites, require complex water distribution and drainage networks with considerable leveling.

The African climate is often severe, with the possibility of intense rainfall and cyclic droughts requiring high safety coefficients in project design.

In addition to these physical constraints, external causes of high investment costs include (a) the overvaluation of most African currencies, which inflates all costs in dollar terms; (b) difficult access and high transportation costs for construction materials to the inland areas and to most irrigation sites; (c) taxes, such as wage, import, and fuel taxes that raise costs and that are rarely waived; (d) the lack of local manufacture of equipment and spares together with supply difficulties, make it necessary for projects to carry heavy stocks; (e) the lack of local equipment sales and service agents; (f) the shortage and high cost of skilled local personnel (mechanics, construction workers) and small contractors; and (g) the use of tied external funds for construction, requiring the purchase of nonstandard equipment with special maintenance and spare part needs.

LOWER IRRIGATION BENEFITS

In addition to the relatively higher cost of irrigation in Africa benefits from irrigation have tended to be lower for several reasons:

(1) Inherently difficult agroclimatic and agronomic conditions, some of which have not been anticipated during design and implementation stages. These include highly variable climatic conditions, particularly for rainfall, surface water flows, temperature, and wind; significant micro-variation in soils within project command areas; severe weed infestation; complex shifts in insect, pest, and disease resistance as greater water control allows more uniform plant stands; and increasing soil salinity and compaction (Moris and Thom 1990).

(2) Lack of appropriate crop varieties and low use of complementary inputs, particularly fertilizer. Although irrigation helps to increase agricultural production even with traditional varieties, high returns to irrigation require high-yielding varieties and substantial fertilizer application. But fertilizer use remains very low in Sub-Saharan African, with about 10 kilograms per hectare, compared to 60 kilograms per hectare in all developing countries; pesticide and herbicide use is even lower. The proportion of farmers planting improved seeds is also low, although it varies by crop. There have been significant successes with hybrid

maize in eastern and southern Africa, cotton in west Africa, potatoes in east Africa, and export crops, such as coffee and cocoa, in east and west Africa. However, there has been limited success in diffusing improved varieties of important food crops, such as roots and tubers, millet, and sorghum. Modern varieties of rice have been adopted on a small percentage of cultivated rice area in Sub-Saharan Africa, and most rice is grown under rainfed conditions. However, there is recent evidence of improved incomes from adoption of modern rice varieties, and recently developed varieties and water control techniques appear to offer considerable potential in irrigated areas (Reardon et al. 1993).

(3) Labor scarcity, which leads to high labor costs and labor bottlenecks at peak seasons. Introduction of irrigation often further concentrates peak planting and harvesting seasons, worsening labor shortages at critical times. In addition, farmers often allocate their scarce labor to nearby rainfed plots, rather than to irrigated plots with riskier high input use and potentially poor performance (and farm returns) due to bad management of a system that is out of their control.

(4) Insecure land tenure and water rights, which reduces incentives to invest in and maintain irrigation facilities and land quality.

(5) Problems in coordination of technical and socioeconomic aspects of irrigation and irrigated farming, combined with lack of experience of African farmers and irrigation managers with these management problems, including scheduling and timing of water releases, arrangements for common services such as field preparation or transport, provision of inputs, and crop marketing (Moris and Thom 1990).

(6) Poor operation and maintenance of irrigation system. At the irrigation scheme level, maintenance may suffer from initial design and construction faults, inadequate recurrent expenditures, lack of equipment, unrealistic expectations of farmer contributions, and failure to understand the importance of routine maintenance. Farmers in turn often fail to maintain the systems because of competition between maintenance tasks and non-irrigated farming, insecurity of tenure or absentee ownership of plots, and the common property nature of maintenance, which is not effective unless all farmers contribute (Moris and Thom 1990).

(7) Overvalued exchange rates have acted as a disincentive to agricultural production. Inflationary urban expenditures have drawn labor from agriculture, raising labor costs. Policies have often been highly variable, leading to incorrect expectations regarding prices and other incentives. A World Bank review found that medium-level overvaluation of currency (20 to 200 percent) is associated with an average reduction in the returns to irrigation of 16 percent, and that high overvaluation (more than 200 percent) is associated with a reduction in returns of 23 percent (Jones 1995).

RATES OF RETURN TO IRRIGATION INVESTMENT

With highly variable costs and benefits from irrigation, it is not surprising that economic rates of return also show mixed success of large-scale projects in Sub-Saharan Africa. A review of the rates of return for 15 projects with World Bank funding showed both relatively good returns to some of the projects, and the very substantial risk of negative returns. Five of the systems had rates of return in excess of 10 percent, 4 were positive but below 10 percent, and 6 had negative returns (Barghouti and LeMoigne 1990). An FAO review of investment performance showed a somewhat higher success rate, with 50 percent of African irrigation projects achieving re-estimated rates of return higher than the appraised rate (FAO 1989, cited in Brown and Nooter 1992). Moreover, a comprehensive review of World Bank projects showed average rates of return for 11 gravity projects of 9 percent, for 7 pump projects of 13 percent, and 5 mixed projects of 14 percent (Jones 1995).

Overall, these results indicate that large-scale irrigation faces significant constraints. The difficult physical environment places high demands on project design and implementation. However, even under difficult physical conditions, successful investment in large-scale systems is feasible with good project design and implementation. Removal of other constraints and a favorable policy environment are essential. We explore the implications of these findings for future investment strategies below.

GOVERNMENT-CONTROLLED SMALL-SCALE IRRIGATION

The highly mixed, and sometimes disastrous, experience with large-scale systems in Africa led to a new interest in the potential for small-scale irrigation beginning in the 1980s. Underhill (1990) summarized the potential advantages of small-scale irrigation: small-scale technology can be based on farmers' existing knowledge; it is more compatible with the existing physical and human environment; local technical, managerial, and entrepreneurial skills can be utilized; migration or resettlement of labor is not usually required; the planning and development of small-scale systems is more flexible; social infrastructure requirements are reduced; and external input requirements are lower.

The evidence on government-controlled small-scale irrigation in Sub-Saharan Africa, however, suggests that these potential advantages are often not realized. The mode of implementation has effectively eliminated the potential advantages, so that in many cases small-scale irrigation has been just "a miniature version of the technically sophisticated, fully-controlled irrigation promoted in larger projects" (FAO 1986). A comparative review of large and small government-managed irrigation systems in Kenya concluded that big and small systems often share a number of common characteristics: high capital cost per hectare and per farmer; bureaucratic, costly, and inefficient management; low technical efficiency; low settler incomes; and low, zero or negative returns for government investments (Adams 1990).

These concerns are borne out by cost and benefit estimates for government-run irrigation systems. Investment costs for small-scale schemes show the same wide variability and high end as for large-scale schemes. The cost of the cluster of small-scale schemes in the Turkana region of Kenya has been estimated at US$63,000 per hectare in 1983 prices (Adams 1990). The estimated costs of the Malka Dakaa small-scale systems in northern Kenya range from US$16,000 per hectare to US$30,000 (Moris and Thom 1990). A more typical range of investment costs is the US$5,000-$7,500 per hectare of Niger's small-scale irrigation and Kenya's Kibirigwi project. Three small-scale projects in Burkina Faso had estimated costs of US$4,000, US$4,500, and US$8,700 per hectare, similar to the central range of costs for large-scale system described above. With the very small-scale farmer-managed systems relying on small pumps or simple diversion weirs, costs may be considerably lower, around US$2,000-$3,000 per hectare (FAO 1995b).

System performance, in terms of crop yields and intensities on small-scale schemes, also span the wide ranges, for essentially the same reasons cited above for large-scale systems. As small irrigation systems are often widely dispersed, they may have even greater problems in obtaining inputs, services, and timely technical advice than large-scale systems (FAO 1986). These problems have been reflected in poor performance and low economic returns to many government-controlled small-scale schemes.

FARMER-CONTROLLED SMALL-SCALE IRRIGATION

Can the potential advantages from small-scale irrigation be achieved more regularly than described above? There is considerable evidence that farmer-controlled small-scale irrigation has a better performance record than government-controlled small-scale systems. These farmer-owned and -managed schemes also sometimes fail, but the failed systems do not continue to operate to be observed and analyzed; they simply disappear. In Burkina Faso, small-scale irrigation covered 6,200 hectares in 1956 but declined to 1,500 hectares in 1961, before partially recovering to about 3,000 hectares in the mid 1980s (Brown and Nooter 1992). The substantial small-scale sector that does exist, generally without significant government support, indicates that these systems are economically viable.

These types of schemes include (a) systems ranging from 1 to 100 hectares, with the larger systems within this range controlled by water user associations, cooperatives, voluntary groups, and other associations, and the smaller schemes controlled by individual farmers; and (b) very small "garden" irrigation (less than 0.5 hectares to a few square meters), variously called *bolilands*, *dambos*, *bani*, or other regional names. Irrigation methods include simple river diversions, lifting with *shadouf* or small pumps from shallow groundwater, rivers, lakes, swamps, or seasonally flooded depressions.

Although time series data are scarce, it appears that areas under farmer-controlled small-scale systems have grown rapidly over the past decades, and account for a large and growing share of irrigated area in Sub-Saharan Africa. Examples of successful small-scale irrigation can be found in many countries. In Niger, privately developed irrigation, relying on private sector provision of inputs and using inexpensive pumps lifting from shallow groundwater has increased rapidly to 60,000 hectares (Brown and Nooter 1992). Farmer-initiated and controlled small-scale irrigation development in the *fadamas* (seasonally flooded plains) of northern Nigeria has been extraordinarily rapid. Some 780,000 of 830,000 hectares of irrigated area in Nigeria are accounted for by small-scale *fadama* irrigation, despite heavy public investment in large-scale irrigation (Lele and Subramanian 1990). In Mauritania, on the other hand, there has been important synergy between large-scale investment and small-scale farmer developed irrigation. A land law reform in 1984 provided land rights to people who improved the land through irrigation or other investments, providing new incentives for private irrigation. The completion of the Diama and Manantali dam reservoirs on the Senegal River in 1988 improved water security and increased planting flexibility, further spurring downstream private investment in irrigation facilities (Brown and Nooter 1992).

In Sierra Leone, *bolilands*, which are low, saucer-shaped swamp grasslands, have the potential for 30,000 hectares of irrigated rice cultivation, and nearly 60 percent of this potential is already under cultivation. The *dambos* of Central and South Africa are physically similar to the *bolilands*, and account for about ten percent of the total land surface (Underhill 1990). *Dambo* wetlands have been increasingly used for irrigated farming, despite laws against such use in come countries. In Zimbabwe, *dambos* (locally called *banis*) have been intensively and successfully farmed, apparently in a sustainable fashion that does not damage soil and water resources (Andreini 1993).

Small streams have also been developed for local irrigation by farmers throughout Africa. Nearly 19,000 hectares of valley bottom lands in the Ivory Coast are irrigated by diversion of water from small streams, sometimes involving dam construction. These 10-15 hectare systems are relatively inexpensive, except for the dams, and rely heavily on farmer participation. Although the construction of these small dams is relatively expensive, they have proved profitable where groups of farmers have cooperated and suitable dam sites have been found (Underhill 1990).

What accounts for the relative success of farmer-controlled small-scale systems? Brown and Nooter (1992) identify the following common characteristics: (a) technology is simple and low cost, usually consisting of small pumps drawing water from shallow aquifers or rivers and streams; (b) the institutional arrangements for operating the system are private and individual; (c) the supporting infrastructure is adequate to permit access to inputs and to markets for the sale of surplus production; (d) the systems generate high and timely cash returns to farmers; and (e) the farmer is an active and committed participant in project design and implementation (Brown and Nooter 1992).

The evidence thus indicates considerable potential for expansion of small-scale farmer-controlled irrigation. The question remains as to whether the government can assist in developing this sector through initiatives that build upon and support existing, informal farmer-controlled schemes; or if such an attempt to support this sector would simply undermine its strengths (Adams 1990).

Coward (1986) has pointed out a useful distinction between direct and indirect investment strategies for assisting traditional or informal small-scale irrigation systems. Under a direct investment strategy, government technical agencies use their own budgets and staffs to design, construct, and operate "upgraded" irrigation facilities within the traditional irrigation systems that are then government-owned. In the indirect investment strategy, the government makes resources available to the traditional systems (in the form of grants, loans, technical expertise) to implement irrigation development on works owned and controlled by individual users or groups of users. Based on case studies in Southeast Asia, the indirect approach seems clearly superior. The direct investment approach often replaces efficient traditional technology with high-cost and ineffective technology and leaves the government with high recurring costs for staffing and managing the systems. The indirect approach instead leaves ownership and management of the system with the traditional group and often leads to complementary investment of local resources. The indirect investment approach needs to be further studied in the African context to determine its strengths and weaknesses and the situations under which it may be a suitable policy. However, available evidence indicates that the indirect investment approach is the preferable approach to assisting farmer-controlled irrigation.

In Nigeria, the *fadama* development program incorporated several aspects of the indirect investment approach and has achieved some significant successes. In the early 1980s, small inexpensive petrol pumps appeared on the market in Nigeria and farmers spontaneously replaced their traditional water lifting devices. The success of the small pumps encouraged the government to launch a National Fadama Development Project (NFDP) with the objective to accelerate *fadama* development through small-scale irrigation and to install about 50,000 tubewells irrigating about 100,000 hectares. The program is based on the use of simple technology for shallow tubewells, dissemination of techniques for tubewell irrigation, privatization of drilling activities, and improved irrigation management through water users' associations (WUAs).

The prospects for community-managed surface systems appear most promising where the national regime encourages the formation of village-level committees or village governments, as Tanzania has since the mid-1970s. The key point is not whether the institutional form is indigenous or introduced, but rather that the locus of control remains within the community (Moris and Thom 1990).

By contrast, it is very difficult to deal with a dispersed network of very small irrigation units and farm plots by means of modern engineering approaches. Even when suitably "small-scale" units are designed, they require machinery, construction and a financial structure quite different from most indigenous African systems. The relatively poor results of donor attempts to assist "swamp rice" projects in west Africa, and of externally sponsored small projects in Niger, Senegal, and Kenya, confirms the difficulty of the direct investment approach.

GROUNDWATER

In Sub-Saharan Africa, the distinction between groundwater irrigation and small-scale seasonally flooded irrigation is often blurred, and several performance aspects of both irrigation types were discussed above. Shallow groundwater has been exploited widely by small farmers, lifted either manually using the traditional *shadouf* or mechanically through use of shallow wells and gasoline-powered centrifugal pumps. Continued expansion of pump irrigation is likely to be locally and regionally important, particularly in valley bottomlands and along the alluvial beds of some of the major rivers where shallow, good quality groundwater can be found.

There remains considerable scope for dissemination of improved technology for groundwater irrigation. Traditional Asian technologies such as "sludging" and more modern hand techniques such as hand augering, washboring, and vibro-bailing could profitably be disseminated much more widely for more efficient shallow lifts. Government extension efforts in groundwater irrigation techniques could have a high payoff. A common problem for all developing regions, and particularly acute in Sub-Saharan Africa, is that the actual extent of groundwater storage and recharge is poorly understood. Sharply increased investment in exploration and evaluation of aquifer and wetlands properties, including geometry, continuity, boundaries, and hydraulic characteristics; and recharge rates, including spatial and temporal variability, could have high payoffs (Carter and Howsam 1994).

Although groundwater irrigation can yield high returns regionally and locally, it is unlikely to account for a large share of crop production in Sub-Saharan Africa. Groundwater aquifers in much of the region are small and discontinuous, and with slow recharge. Groundwater yields in some of the sedimentary basins such as the Chad and Senegal are somewhat better, but in many cases the water may be over 100 meters deep and therefore costly to extract (FAO 1986).

By contrast, with careful management, groundwater could be a significant source of new water supplies in North Africa. Large aquifers underlying this region include the Eastern Erg and the Nubian Aquifers. The Eastern Erg in Algeria and Tunisia covers an area of almost 400,000 square kilometers, and stores an amount of water equal to about four times the average annual renewable supply of the entire North Africa and Middle Eastern region. Only 0.04 percent of this volume is recharged annually, so this is essentially fossil water. The Nubian Sandstone Aquifer underlies parts of Egypt, Libya, and Sudan, extending over an area of 1.8 million square kilometers. The volume of stored water is nearly 20 times the average annual renewable supply for North Africa and the Middle East, and the aquifer has an annual recharge rate equal to about 2.5 percent of its volume, so this resource could be of great value if exploited prudently. However, concerns have grown over Libya's plans to transfer massive amounts of this water from southeastern Libya to the country's coastal region via the so-called Great Man-made River Project, which could substantially reduce the groundwater reserves in the two other riparian countries.

Because of these large fossil aquifers in North Africa, extensive investigation is required to determine their characteristics, possible exploitation rates, and the potential impacts on neighboring countries. In general, the large aquifers have shallow gradients and low permeability, so pumping does not quickly affect water levels and volumes over long distances. However, it can lead to decline in local watertables and to the exhaustion of a specific wells. Given the size and the great depth of these aquifers, constraints on exploitation are likely to be economic rather than physical (World Bank 1994).

Despite the extensive groundwater resources in North Africa, there is already considerable evidence of groundwater overdrafting and degradation of water quality. Groundwater is depleted when pumping rates exceed the rate of natural recharge. Pumping of fossil groundwater constitutes water mining, one-time extractions from a depletable resource. While mining of both renewable and non-renewable water resources can be an optimal economic strategy, it is clear that groundwater mining is excessive in many instances. Overdrafting, or the mining of groundwater at a rate higher than recharge, increases pumping lifts and costs because of the lowered water table, causes land to subside (sometimes irreversibly damaging the aquifer), and induces saline intrusion and other degradation of water quality in the aquifer. In the Nile delta, groundwater problems are being exacerbated by reduced flows in the river, which have prevented normal discharge (USAID 1993).

Fossil aquifers, which are typically deep underground, and which receive little or no recharge, are already being utilized for irrigation in North Africa. Egypt is irrigating 17,000 hectares of cropland from fossil aquifers, and has plans to increase these areas several-fold (Abu-Zeid 1992). Fossil aquifers are also exploited in Kufrah, Libya (USAID 1993).

IRRIGATION MODERNIZATION AND REHABILITATION

When net returns to investment in new irrigation construction decline, it is natural to turn to rehabilitation projects as investment alternatives; which are usually cheaper as they can take advantage of substantial sunk costs in existing systems. Sometimes the intent is simply to restore the project to its original design specifications. More often, recognizing the need for changes in the design, systems are also "modernized" in the rehabilitation process. Unfortunately, however, one of the most powerful tools for making the redesign an improvement--drawing on the knowledge and experience of the farmers who have been using the system over the years--is seldom availed of in a systematic manner, and modernization planning is approached in much the same way as the design of an entirely new system.

To understand the potentials and pitfalls for rehabilitation and modernization, it is useful to turn to the Asian experience. Rosegrant and Svendsen (1993) found a wide range of economic returns to rehabilitation and management improvement projects, and identified selectivity in project selection and design as important success factors. Many rehabilitation projects in Sub-Saharan Africa have been large-scale and capital-intensive, aiming at a thorough remake of the system, and rehabilitation and modernization costs have been high, averaging US$2,100 per hectare of service area (FAO 1995b). These investments have been subject to the same type of rent-seeking, delays, and cost overruns that characterize much new system construction. A better approach would be to experiment with more selective lower-cost rehabilitations. An excellent example of a low-cost approach in Sri Lanka has been examined by Aluwihare and Kikuchi (1991), who found that rates of return on water management improvement projects with minimal rehabilitation were several times higher than rates on more comprehensive rehabilitation projects.

Innovative thinking and research is needed to select the appropriate intervention points within systems, to identify low-cost rehabilitation options to implement at these intervention points, and to develop improved appraisal methodologies to select appropriate systems for intervention. Barriers between rehabilitation projects and management improvement projects must be knocked down; a wide range of possible changes and their interrelationships must be considered; project appraisal and design should be tailored towards improvement work in existing systems; farmers, who have valuable knowledge of system deficiencies and likely reactions to changes in system configuration and operating rules, should be involved extensively in this process; and project engineers should be continuously working together with economists from the start of the irrigation project, so that the net benefits from individual project components can be evaluated and components added or deleted based on their contribution to total project benefits. Promising technologies, which have been developed in recent years, should be systematically examined for their potential of improving irrigation performance, in particular the performance of water allocation and distribution systems. This must be done in conjunction with management research, since effective technologies will not be adopted by individual farmers but by bureaucratically organized agencies that do not operate in a market environment.

In sum, while the generalized high level of benefits expected by some observers from performance improvement activities have not been realized, productive investments to improve irrigation performance can be made, and significant gains achieved. Success of irrigation improvement projects will involve an intelligent selective approach--one based on a menu of choices which spans a wide range of possible interventions, flexible and broadly participatory design approaches, and attention to all aspects of the policy environment which surrounds irrigated agriculture. In general, successful performance improvement projects will pay a relatively higher share of attention to policy, managerial, and institutional issues, and relatively less to comprehensive physical improvements than in the past.

9. APPRAISING FUTURE INVESTMENT IN IRRIGATION

INTRODUCTION

In the following, the arguments that there are factors in the evaluation process for irrigation investments which have led to an undervaluation of irrigation benefits and a consequent under-investment in irrigation in Africa are reviewed. If valid, these arguments would suggest that the revision of procedures would improve the returns to and feasibility of irrigation investment. Based on this review, rates of return to investment in irrigation will be explored under alternative assumptions, regarding irrigation investment costs, incremental production generated by the project, and world crop prices.

ARGUMENTS FOR UNDER-INVESTMENT IN IRRIGATION IN AFRICA

At least four arguments can be advanced to suggest that current investment procedures lead to under-investment:

(1) World prices are endogenous to total irrigation investment. In most project evaluations undertaken by international donors and national governments, the world commodity price projections of the World Bank are utilized as shadow prices. For any given irrigation project it can be assumed, for purposes of cost-benefit analysis, that these projected world prices are exogenous, since the incremental output from an individual project will not affect world prices. However, world prices are partly a function of total irrigation (and other) investments. As described above, irrigation investment decisions by international lenders and by many countries are responsive to world prices. A large downward shift in irrigation investment due to declining prices will tend to reduce production, and to put upward pressure on prices. These feedback effects from irrigation investment to prices should be considered in setting the shadow price for commodities in project analysis, but evidence indicates that they are not fully accounted for in the commodity price projections.

Warr (1990), in an analysis of World Bank grain price projections, shows that the expected value of projected price changes exceeds actual price changes; thus there is a tendency for projected price changes to overestimate the magnitude of actual price changes. Warr concludes that the World Bank price forecasts do not make efficient use of available information. This result is consistent with a failure to fully account for the feedback effects between prices and irrigation investment, and implies that current rice and wheat price projections overstate the degree of decline in future world prices.

Would explicit recognition and analysis of the world prices of rice and wheat as a function of irrigation and other investments make an important difference in the shadow prices? The alternative projections presented above show that world prices are not sensitive to levels of irrigation investment in Africa. The share of African irrigated crop production in total world food production is simply too small for shifts in investment patterns to have much influence on world prices.

(2) Domestic prices are endogenous to irrigation investment. In many African countries, the process of commercialization has been derailed by intersectoral and interregional market rigidities. Unlike the quite open economies of much of Asia, most African countries are only "semi-open," because transport and other marketing costs often double or triple both African export values, f.o.b., relative to farm gate prices, and consuming point retail prices for importables relative to their c.i.f. African port prices. High marketing costs are a function of structural factors, such as poor infrastructure, large distances, and the low volume of production; of direct policies, such as those regulating traders; and of sectoral policies, such as taxation of spare parts for trucks (Delgado 1995).

Thus, import parity prices for crops produced in irrigation projects located in the interior will be far higher than prices at the port, and accounting for these differences is standard practice in cost-benefit analysis. However, a possibly more significant implication of the semi-open nature of many African economies is the potentially large spillover benefits from public investment in irrigation.

The semi-open nature of many African economies implies that a failure to induce productivity growth in the non-tradable food crop sector can choke-off an incipient boom in a commercializing export sector. Since many wage goods, such as staple foods, are effectively non-tradable, the increased demand for food due to an export boom will bid up food prices relative to prices of agricultural exports. Higher prices for food are then likely to lead to higher wage demands in Africa, given the importance of food in household budgets. The competitiveness of exports will be hard to maintain if the supply of non-tradables is not sufficiently responsive to prices. Given the structural rigidities in markets, a lagging sector or region acts as a drag on commercialization of other sectors or regions. Because of these structural problems, crop- and region- specific government policies such as irrigation investment have a significant role to play in providing incentives for commercialization and diversification in many African economies (Delgado 1995). These spill-over benefits are not captured in cost-benefit analysis, and suggest an underestimation of returns to irrigation under African conditions.

(3) Risk and uncertainty. Cost-benefit analysis generally is done using expected prices, costs, and benefits, without formal consideration of the probability distributions of outcomes. To the extent that distributions of prices or returns are asymmetric or covariant, it is appropriate to take more explicit account of risk and uncertainty. Mitchell (1991) has undertaken an initial exploration of this issue with respect to Philippine rice import costs. He showed that Philippine rice imports are positively correlated with world rice prices, so the long-term marginal cost of rice imports is higher than the average world rice price, by 5-10 percent. This effect arises from positive covariance between Philippine and world rice production. The shadow price of rice for the Philippines should therefore be higher than projected world prices. Similar evidence could be found in major maize imports in southern Sub-Saharan Africa during a catastrophic drought at the beginning of the 1990s, at a time when world prices soared. Thus, projected world prices could understate long-run shadow prices of staple crops.

(4) Secondary benefits of irrigation. Cost-benefit analysis generally measures only the direct benefits of investment projects. In addition to the spill-over affects due to the semi-open nature of many African economies, large investment projects also tend to cause an increase in economic activity in the rest of the economy, and this increase may, in turn, induce increased productivity in the original project. Thus, the total effects of the project on incomes and the net demands for goods and services in the economy will be different from its direct effects. For example, Bell, Hazell, and Slade (1982) found, in an analysis of the Muda irrigation project in Malaysia, that the indirect effects were large: about 80 cents of additional value added was generated in the region for each dollar of value added generated directly.

However, secondary benefits are not limited to irrigation investment. Ahmed and Hossain (1990) have shown the importance of secondary benefits of rural roads and infrastructure in Bangladesh, which include an important influence on the diffusion of technology and the efficiency of resource use, improved distribution of fertilizers, an increased rate of adoption of small-scale irrigation devices, and improved labor mobility, credit availability, and market information. There appears to be no evidence of a higher propensity for generation of secondary benefits from irrigation investment compared to other types of large-scale investment.

Overall, it is likely that standard cost-benefit analysis understates to some extent the returns to both irrigation and other investments which are locally or regionally large enough to have substantial spill-over benefits, particularly in the context of the semi-open African economies.

RETURNS TO IRRIGATION INVESTMENT: A STYLIZED COST-BENEFIT ANALYSIS

A proper cost-benefit analysis (CBA) is by nature specific to any given investment project. Every river basin is different, and the appropriate choice of system size, operational characteristics, and resulting economic rates of return in any given basin will be determined by conditions unique to that basin. However, a stylized CBA of a "generic" irrigation project in Africa can shed some light on the benefits that must be obtained to generate acceptable economic rates of return. This exercise is undertaken here, examining the implications for economic returns of a typical phasing pattern of investment in irrigation systems and the subsequent pattern of benefit flows due to increased agricultural land productivity. The analysis aims at identifying the incremental levels and values of production necessary to achieve predetermined or target internal rate of returns (IRR) for different levels of irrigation investment.

A typical pattern of investment flow in irrigation system construction (costs) and incremental agricultural production (benefits) is depicted in Table 14. The construction period extends up to 8 years and benefits start to accrue in the fourth year, extending over 30 years of project life. The analysis is for a land unit of 1 hectare, so that irrigation investment costs are in US$ per hectare of command area. Benefits are incremental value of production for one hectare, net of incremental production costs, and operations and maintenance costs of the irrigation system.

Table 14 Flow of costs and benefits, stylized irrigation project in Sub-Saharan Africa

Project year	Investment	Incremental value of production
	(% of total outlay)	*(% of annual value)*
1	5	-
2	5	-
3	10	-
4	15	10
5	15	20
6	20	30
7	20	45
8	10	55
9	-	75
10	-	85
11	-	95
12	-	100
13-30	-	100

Source: Authors' calculations.

The net annual values of incremental production and the equivalent yield increment needed to generate IRRs of 12 percent, 10 percent, 8 percent, and 6 percent are calculated for rice and maize. Two price assumptions are used here, one at the border (c.i.f.) and one at the interior market. For rice, the border price is set at US$309 per metric ton, based on the 1995 world price for 10 percent brokens of US$289 per metric ton and US$20 per metric ton of freight cost. With the addition of marketing costs, including transport, storage and handling, the interior market price for rice is expected to be 60-64 percent higher and is estimated at US$500 per metric ton. The border price of maize is estimated at US$123 per metric ton and the interior market price at US$200 per metric ton. Total incremental production costs and operations and maintenance costs of irrigation are assumed to be 30 percent of production for rice and 15 percent for maize. In addition, a 68 percent milling recovery rate is assumed for rice and the value for the by-products is expected to cover the cost of processing.

The CBA results are presented in Tables 15 and 16 for rice, and Tables 17 and 18 for maize. These tables present the incremental yield levels required to achieve the target IRRs at various levels of irrigation investment at given output prices. The average investment cost for medium- to large-scale irrigation systems is US$8,300 per hectare and the average irrigated rice yield in Sub-Saharan Africa is 2.7 metric tons per hectare. Table 15 shows that, at border prices equivalent to import parity at the coast, either lower than average investment costs, or higher than average incremental rice yields are required to obtain an "acceptable" rate of return of 10 percent. Even with costs of US$6,000 per hectare, an average annual incremental rice yield of 5.3 metric tons per hectare, equivalent to double-cropping at the average rice yield would be required to generate a 10 percent rate of return. The picture is much more favorable if the import parity price reflects the conditions in the interior. Even with investment costs of US$10,000 per hectare, a project which achieves a reasonable yield and cropping intensity can be justified (Table 16).

A similar picture emerges for maize, which has an average yield under irrigated conditions of 3.1 metric tons per hectare in Sub-Saharan Africa. At coastal port import parity prices, extraordinarily high incremental maize yields would be necessary to justify a project at average investment costs (Table 17), whereas acceptable rates of return can be achieved with reasonable yield levels at import parity prices including tranportation costs to the interior (Table 18). These results, however, imply that irrigated maize would not be competitive for exports, since the export prices would be much lower than import parity prices.

STRATEGIES FOR FUTURE IRRIGATION INVESTMENT

Selective development of new surface irrigation can still play a role in future water resource development in Africa, particularly in Sub-Saharan Africa. A faster expansion of irrigation can have an important role in reducing projected cereal import demands. The problems described above with both large- and small-scale irrigation projects should not deter investors from supporting future projects; historical experience also provides examples of success stories and lessons that can assist in identifying relevant investment strategies.

Table 15 Rice at the border: Net incremental value of rice production and paddy yield equivalent required to achieve target rates of return (IRR)

Investment Cost	IRR=12%		IRR=10%		IRR=8%		IRR=6%		IRR=4%	
	Benefits	Yield	Benefits	Yield	Benefits	Yield	Benefits	Yield	Benefits	Yield
US$/ha	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*
15,000	2,311	15.71	1,953	13.28	1,625	11.05	1,330	9.04	1,069	7.26
12,000	1,848	12.57	1,562	10.62	1,300	8.84	1,064	7.24	855	5.81
10,000	1,540	10.47	1,302	8.85	1,084	7.37	887	6.03	712	4.84
8,000	1,232	8.38	1,041	7.08	867	5.89	709	4.82	570	3.87
6,000	924	6.28	781	5.31	650	4.42	532	3.62	427	2.91
4,000	616	4.19	521	3.54	433	2.95	355	2.41	285	1.94
2,000	308	2.09	260	1.77	217	1.47	177	1.21	142	0.97
1,000	154	1.05	130	0.89	108	0.74	89	0.60	71	0.48

Note: Benefits are the incremental value of production net of production costs and O&M costs of irrigation.

Assumptions:

Price of Rice:	309 US$/mt
Milling rate:	68 %
Incremental cost of production:	63 US$/mt

Source: Authors' calculations.

Table 16 Rice at interior markets: Net incremental value of rice production and paddy yield equivalent required to achieve target rates of return (IRR)

Investment Cost	IRR=12%		IRR=10%		IRR=8%		IRR=6%		IRR=4%	
	Benefits	Paddy yield	Benefits	Paddy yield	Benefits	Paddy yield	Benefits	Paddy yield	Benefits	Paddy yield
US$/ha	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*
15,000	2,311	8.49	1,953	7.18	1,625	5.98	1,330	4.89	1,069	3.93
12,000	1,848	6.80	1,562	5.74	1,300	4.78	1,064	3.91	855	3.14
10,000	1,540	5.66	1,302	4.79	1,084	3.98	887	3.26	712	2.62
8,000	1,232	4.53	1,041	3.83	867	3.19	709	2.61	570	2.10
6,000	924	3.40	781	2.87	650	2.39	532	1.96	427	1.57
4,000	616	2.27	521	1.91	433	1.59	355	1.30	285	1.05
2,000	308	1.13	260	0.96	217	0.80	177	0.65	142	0.52
1,000	154	0.57	130	0.48	108	0.40	89	0.33	71	0.26

Note: Benefits are the incremental value of production net of production costs and O&M costs of irrigation.

Assumptions:

Price of Rice:	500 US$/mt
Milling rate:	68 %
Incremental cost of production:	68 US$/mt

Source: Authors' calculations.

Table 17 Maize at the border: Net incremental value of maize production and yield equivalent required to achieve target rates of return (IRR)

Investment Cost	IRR=12%		IRR=10%		IRR=8%		IRR=6%		IRR=4%	
	Benefits	Maize yield	Benefits	Maize yield	Benefits	Maize yield	Benefits	Maize yield	Benefits	Maize yield
US$/ha	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*
15,000	2,311	22.10	1,953	18.68	1,625	15.55	1,330	12.72	1,069	10.22
12,000	1,848	17.68	1,562	14.94	1,300	12.44	1,064	10.18	855	8.18
10,000	1,540	14.73	1,302	12.45	1,084	10.36	887	8.48	712	6.81
8,000	1,232	11.79	1,041	9.96	867	8.29	709	6.79	570	5.45
6,000	924	8.84	781	7.47	650	6.22	532	5.09	427	4.09
4,000	616	5.89	521	4.98	433	4.15	355	3.39	285	2.73
2,000	308	2.95	260	2.49	217	2.07	177	1.70	142	1.36
1,000	154	1.47	130	1.25	108	1.04	89	0.85	71	0.68

Note: Benefits are the incremental value of production net of production costs and O&M costs of irrigation.

Assumptions:

Price of Maize:	123 US$/mt
Incremental cost of production:	63 US$/mt

Source: Authors' calculations.

Table 18 Maize at interior markets: Net incremental value of maize production and yield equivalent required to achieve target rates of return (IRR)

Investment Cost	IRR=12%		IRR=10%		IRR=8%		IRR=6%		IRR=4%	
	Benefits	Maize yield	Benefits	Maize yield	Benefits	Maize yield	Benefits	Maize yield	Benefits	Maize yield
US$/ha	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*	*US$/ha*	*mt/ha*
15,000	2,311	12.84	1,953	10.85	1,625	9.03	1,330	7.39	1,069	5.94
12,000	1,848	10.27	1,562	8.68	1,300	7.22	1,064	5.91	855	4.75
10,000	1,540	8.56	1,302	7.23	1,084	6.02	887	4.93	712	3.96
8,000	1,232	6.85	1,041	5.79	867	4.82	709	3.94	570	3.17
6,000	924	5.13	781	4.34	650	3.61	532	2.96	427	2.37
4,000	616	3.42	521	2.89	433	2.41	355	1.97	285	1.58
2,000	308	1.71	260	1.45	217	1.20	177	0.99	142	0.79
1,000	154	0.86	130	0.72	108	0.60	89	0.49	71	0.40

Note: Benefits are the incremental value of production net of production costs and O&M costs of irrigation.

Assumptions:

Price of Maize:	200 US$/mt
Incremental cost of production:	20 US$/mt

Source: Authors' calculations.

Furthermore, ongoing macroeconomic reforms and institutional improvements are removing some of the external causes for poor performance in the past. A key lesson is that effective project design and implementation are absolutely essential to achieving acceptable rates of return, due to the difficult physical environment and relatively high investment costs.

The evidence indicates that, fundamentally, the small versus large distinction is not very useful in the Sub-Saharan African context. It is not so much the size of the irrigation system that determines its success, but a host of institutional, physical, and technical factors. Every river basin is different, and the appropriate choice of system size and operational characteristics in any given basin is likely to be determined by conditions unique to that basin. Large-scale irrigation should be carefully assessed as a possibility for some locations. A comprehensive approach to project design and evaluation should be taken that ensures quantification of full benefits, including not only irrigation benefits, but health, household water use, and catchment improvement benefits (Jones 1995), and full assessment of, and compensation for, negative environmental and resettlement costs. Farmer participation in project design and development should be greatly expanded. Projects that require high levels of social investment, but are supported only by direct irrigation benefits, will not have acceptable rates of return. Either the social infrastructure must have additional indirect evaluated benefits, which justify its inclusion in the project; or irrigation projects will have to be built where sufficient infrastructure already exists.

A high priority should be given to indirect investments, in the form of grants, loans, and technical expertise, for expansion of farmer-controlled small-scale projects, especially in countries and regions with poor potential for rainfed agriculture. Initial grants or loans to establish economically sustainable technologies, for example to purchase a small tubewell, appear reasonable given the absence or weakness of credit markets in much of Africa. However, ongoing subsidies on recurring inputs, such as energy, which only maintain otherwise unsustainable technologies, are not justified. Expansion of small-scale farmer-controlled irrigation would have the additional benefit of acquisition of experience, not only with respect to the proposed technologies, but also with respect to the economic, social, and institutional aspects of implementation.

Existing irrigation systems should be analyzed to determine possibilities of improvement, and priorities for rehabilitation, expansion, and modernization. Rehabilitation and modernization projects must be selected carefully. Higher-cost rehabilitations would need to generate very large incremental benefits to be justified. Investments in rehabilitation and modernization should be used to provide incentives for management reform in existing bureaucratically-run irrigation systems. Without such reform, it is unlikely that the benefits from rehabilitation will be adequate to justify the investments. Reforms should be oriented towards getting the highest returns from existing and incremental investment, and must handle technical requirements (spare parts, new equipment), policy issues (cost recovery, incentives, marketing, and pricing), and institutional questions such as operation and maintenance, farmers' participation, and extension services (Barghouti and Le Moigne 1990).

The public sector can also play an important supporting role in the expansion of groundwater irrigation. Governments could increase investment in exploration and evaluation of aquifers and soils to determine the extent of groundwater storage and recharge. Expanded government efforts to extend and disseminate groundwater irrigation technologies and techniques could have a high payoff. Pilot schemes in groundwater development would assist in the development and dissemination of appropriate designs.

10. SUPPLY AUGMENTATION: URBAN WATER SUPPLIES AND NON-TRADITIONAL METHODS

URBAN WATER SUPPLIES: REALLOCATION FROM AGRICULTURE?

A fundamental question is the degree to which demand for urban water can be met from new sources, from savings from existing waste and inefficient water use in urban water systems, or from reallocation of water from agriculture. The last two topics are discussed briefly here and in more detail later. Whatever the mix of sources for new urban water supplies, there is general agreement that huge new investments in urban water systems will be necessary. The sewage and wastewater treatment problem has also not been adequately addressed, and as the concentration of pollutants increases to toxic levels, the problem will have to be confronted. Required investments to provide water and sewage treatment facilities for the rapidly growing urban populations in developing countries could be as high as US$500 per person (Seckler 1996). Sectoral funding of the magnitude needed is not likely to be available in Africa (or other regions of the world).

The almost certain inability to identify new water sources and mobilize these levels of funds to meet the rapidly growing demand for water in urban areas means that, in addition to tapping new water sources, there will almost certainly be an increase in the amount of water reallocated from agriculture to domestic and industrial uses. In North Africa, reallocation of water across sectors is likely to be particularly important. This type of reallocation is already happening in developing countries, despite legal and administrative restrictions against it, because of the differential economic value of water in the two sectors. Thus, for example, informal intersectoral water markets have developed in and around the major river basins in Tamil Nadu, India. Despite significant restrictions on the tradability of water in Tamil Nadu, informal water markets have developed in response to increasing water scarcity and to the differential value of water across sectors. Well owners and irrigators pumping from rivers sell water to truckers who transport the water to urban centers, making substantially higher incomes than if all the water had been retained for irrigation (Palanisami 1994).

The key question is not whether reallocation will occur, but whether it will be accomplished in a rational and equitable manner that keeps costs to a minimum or in the ad hoc manner governing most such reallocations today. Intersectoral reallocation of water can be accomplished either through supply management (with top-down reallocation of water between sectors), or through demand management, which uses incentives to induce water to move among competing demands (described in detail later). Since in most African countries agricultural use accounts for more than 80 percent of consumptive use, relatively small transfers of water from agriculture could meet growing urban and industrial demands. For example, in Morocco, a 5 percent transfer of water from agriculture would almost double the total supplies available for the domestic sector (World Bank 1994).

Nevertheless, there are understandable concerns over possible negative direct and indirect effects from water transfers. In addition to direct impacts on agricultural production, water transfers can negatively affect business activities, local government fiscal capacity, and the quality of public services in areas from which water is being transferred because of the reduction in irrigated area or production and can lead to reductions in agriculturally-linked economic activities and in the tax base. In addition, permanent transfer of water rights may limit future economic development in the area of origin and induce out-migration.

However, the limited evidence available seems to indicate that negative effects from water transfers are manageable. One of most important innovations of Chile's water policy, for example, is allowing cities to buy water without having to buy land or expropriate water. Growing cities now buy rights from many farmers, usually buying a small portion of each farmer's total rights. There have rarely been negative effects in the agricultural zones surrounding water-demanding urban areas, because farmers usually sell small portions of their rights and maintain agricultural production with highly efficient irrigation technology for the orchard or vegetable crops grown in those areas (Gazmuri Schleyer and Rosegrant 1996).

In California, indirect economic effects from water transfers using the 1991 California State Emergency Drought Water Bank were small. Farmers who sold water to the Bank reduced farm operating costs by US$17.7 million, or 11 percent, and crop sales by US$77.1 million, or 20 percent. These reductions adversely affected the suppliers of farm inputs and the handlers and processors of farm outputs, but the effects were not large when compared with the agricultural economy in the selling region. Operating costs, crop sales, and agribusiness revenues dropped 2 to 3 percent in selling counties because of the Bank (Dixon, Moore, and Schechter 1993).

DESALINATION

The supply of freshwater through desalination is in essence infinite, but expensive. However, although desalination capacity increased 13-fold from 1970 to 1990, to more than 13 million cubic meters per day, desalinated water accounts for just one-tenth of 1 percent of freshwater use (Engelman and LeRoy 1993; Gleick 1993). Nearly 60 percent of desalination capacity in the world is in the oil-rich, water-scarce Persian Gulf, and much of the rest of the capacity is on island nations and other arid countries (Postel 1992).

Technology for desalination is improving rapidly, but prices remain high relative to the costs of supplying water from other sources. The cost of production, not including transport costs, ranges from US$1.00-2.00 per cubic meter depending on the technology and salt loads in the water (Frederick 1993). Although this is comparable to the costs of new water supplies in some of the most arid areas of the world, it is very high compared to costs from alternative sources in most of the world. And if substantial transportation costs are incurred to pump desalinated water inland, per unit costs increase significantly. Desalination plants also have high capital and energy costs and generate substantial wastes, which could cause significant environmental problems.

In North Africa, desalination has not been used on a large-scale basis. Algeria has a desalting capacity of 176,000 cubic meters per day, Egypt has 67,700 cubic meters per day, and Libya has 619,000 cubic meters per day; but whereas, in Malta, a capacity of 67,000 cubic meters per day accounts for 50 percent of total water supply, the similar capacity in Egypt accounts only for a miniscule amount of total water supply (Gleick 1993). It is likely that in parts of North Africa, use of desalinated seawater will continue to increase rapidly , from a very low base, but this growth will primarily be for domestic and industrial purposes in coastal regions, and will only have a small impact on total water supplies. Desalination will not contribute to water supplies in Sub-Saharan Africa in the near future.

RECYCLING AND WASTEWATER REUSE

After being used once, freshwater can be used again in the same home or factory (usually called recycling), or collected from one or more sites, treated, and redistributed and used in another location (generally called wastewater reuse) (Postel 1992). Both of these concepts are distinct from the reuse of return flows from irrigation when only part of the water withdrawn from a stream or aquifer is consumptively used. The greatest potential for water saving is likely to be industrial recycling, although wastewater reuse can offer significant and increasing savings as the scarcity value of water increases.

Only a small fraction of industrial water used for cooling, processing, and other activities is actually consumed. Although the water may be heated or polluted, it can often be recycled within a factory or plant, thereby getting more output from each cubic meter delivered or allocated to that operation. Developed countries have greatly expanded the use of water recycling in industry. In the United States, between 1950 and 1990, total industrial water use fell 36 percent while industrial output increased nearly 4-fold, mainly due to pollution control laws (Postel 1992). As the African countries, particularly in North Africa, continue their rapid industrialization process, recycling of water can play an important role in conserving water supplies.

Reuse of wastewater has been more limited in Africa. The rate of expansion of wastewater reuse depends on the final quality of the wastewater and on the public's willingness to use these supplies. Although the technology exists to upgrade wastewater for domestic consumption, it is expensive and consumer resistance has been high. In California, which has the highest reuse of wastewater in the United States, wastewater reuse accounts for less than 1 percent of the state's developed water supplies (Frederick 1993).

About 500,000 hectares of cropland worldwide are irrigated by treated municipal wastewater, amounting to only two-tenths of 1 percent of the world's irrigated area. Israel undertakes the largest wastewater reuse effort in the world, treating 70 percent of the nation's sewage to irrigate 19,000 hectares of cropland. Reclaimed wastewater is projected to supply more than 16 percent of Israel's total water needs by the start of the next century. Most of this would be used in agriculture to replace freshwater reallocated to non-agricultural uses (Postel 1992). Wastewater reuse in Africa is rudimentary, and in some parts of North Africa, untreated wastewater has been utilized despite the health hazards. Total wastewater flows in North Africa are rising fast, although they still remain small relative to total water supply (World Bank 1994). Given the relatively high cost of wastewater treatment and transport to agricultural areas, it is unlikely that wastewater reuse will account for an important share of agricultural water supply in Africa.

However, improved wastewater treatment would have significant impacts on water quality and reduce health risks. Uncontrolled water pollution from industrial and domestic sources is likely to reduce the amount of water available for various uses in the future. For example, excessive pollution of drainage waters around Alexandria reduced the lifespan of irrigation pumps from 20 to four years, and required more sophisticated pumps and piping at higher costs (Abu-Zeid 1992).

WATER HARVESTING

Water harvesting, the capture and diversion of rainfall or floodwater to fields to irrigate crops, has been used in Africa for centuries in traditional agriculture. More recently, the improvement and expanded use of such techniques have been helpful in increasing production and farm income in some environments. For example, farmers in the Yatenga Province in Burkina Faso in recent years have begun to use improved versions of their traditional water harvesting techniques. Farmers in this region build simple stone bunds across the slopes of their fields to reduce erosion and help store moisture in the soil. By the end of 1989, farmers in more than 400 Yatenga villages were using these techniques on 8,000 hectares.

Vegetative barriers can also be used for water harvesting. Vetiver grass, native to India and known there as *khus*, has been used in both Africa and Asia. When densely planted along the contours of a sloping field, the grass forms a vegetative barrier that slows runoff, allowing rainfall to spread out and seep into the soil, much the same way as the stone bunds do. In the Machakos District in southern Kenya, farmers use a water harvesting technique called *fanya-juu* terracing, which involves digging a ditch and throwing the soil up-slope to form an earthen wall that maximizes erosion control and rainwater retention. Average corn yields on terraced lands are estimated to be 50 percent higher than on unterraced lands (Postel 1992).

These experiences, among others, show that in some local and regional ecosytems, water harvesting can provide farmers with improved water availability, increased soil fertility, and higher crop production. Water harvesting can also provide broader environmental benefits through reduced soil erosion. However, given the limited areas where such methods appear feasible and the small amounts of water that can be captured, water harvesting techniques are unlikely to have a significant impact on global food production and water scarcity in Africa.

11. DEMAND MANAGEMENT: COMPREHENSIVE WATER POLICY REFORM

INTRODUCTION

Because of the rapidly growing water shortages and the heightened competition for water among alternative uses, comprehensive water policy reform is urgently needed in North Africa, and will be increasingly important for the relatively water-scarce countries of Sub-Saharan Africa as economic development is rekindled. Demand management is essential for saving water in existing uses, increasing the economic efficiency of water use, improving water quality, and promoting environmentally sustainable water use.

POTENTIAL FOR WATER SAVINGS

A large share of water to meet new demand must come from water saved from existing uses through comprehensive reform of water policy. Such reform will not be easy, because both long-standing practice and cultural and religious beliefs have treated water as a free good and because entrenched interests benefit from the existing system of subsidies and administered allocations of water. Furthermore, the gains from demand management will be more difficult to achieve than is suggested by much of the literature. In some river basins, efficiency gains from existing systems may prove to be limited, because whole-basin water use efficiencies are already high due to reuse and recycling of drainage water, even though individual water users are inefficient.

Although individual project performances vary considerably, overall irrigation efficiencies (the product of irrigation system efficiency and field application efficiency) in Sub-Saharan Africa are generally very low, ranging from 20-30 percent (FAO 1986). In North Africa, efficiencies tend to be somewhat higher, for example, 40-45 percent in Morocco. In Israel, Japan, and Taiwan, on the other hand, overall efficiencies range from 50-60 percent (Rosegrant and Shetty 1994). These low water use efficiencies are often cited as evidence that very large savings in water use can be obtained. However, it must be stressed that these water use efficiencies are derived from individual system evaluations rather than from basin-wide assessments. Unmeasured downstream recovery of "waste" drainage water and recharge and extractions of groundwater can result in actual basin-wide efficiencies substantially greater than the nominal values for particular systems. For example, estimates of overall water use efficiencies for individual systems in the Nile basin in Egypt are as low as 30 percent, but the overall efficiency for the entire Nile system in that country is estimated at 80 percent (Keller 1992).

Can real water savings be achieved through demand management? At the water basin level, the actual water losses are the water that flows to water sinks. Three water sinks are generally considered: (1) losses of water vapor to the atmosphere through evaporation from surfaces and the evapotranspiration of plants; (2) flows of water to salt sinks, including oceans, inland seas, and saline aquifers; and (3) pollution of surface and groundwater by salts or toxic elements so that the water becomes unusable (Seckler 1996). In addition to these, it is conceptually useful to consider a fourth sink, which can be called an "economic sink". The economic sink includes water that drains from the system and seeps or percolates into groundwater or other freshwater sinks, but which is not economically feasible to recover because the cost of reuse (that is, through the installation and operation of a tubewell) is too high. This water is physically available for reuse and thus it is not a true loss to the system, but it will not be used unless demand management is reformed. Moreover, this water can be truly lost to the system through evapotranspiration if it underlies land covered with nonproductive vegetation and weeds.

Conceptually, the economic sink is analogous to the pollution sink. The degree of pollution is a continuum: at low levels of pollution, the water remains reusable, but the effective cost per unit of that water is higher because crop yields per unit of water will be lower. Thus, at low levels of pollution, economic costs are imposed by the initially high withdrawals that lead to drainage, reuse, and pollution, but there are no physical losses of water from the system.. (It could be argued, however, that there are quality-related physical losses, since it takes more polluted water to generate a unit of crop output.) However, with continued reuse, pollution passes a threshold where the water becomes unusable and is lost to the system.

Similarly, the economic feasibility of reuse is a continuum: when the cost of reuse is relatively low, water will be reused and will not be physically lost to the system (although again, economic costs are imposed by the initially excessive water withdrawal). However, when the cost of reusing drainage water becomes high enough (because of, for example, physical characteristics of aquifers, deep percolation, high lifts, field slopes), a threshold is passed at which the water becomes uneconomical to use and becomes effectively sequestered. Within any given environment, the greater the difference between the true scarcity value of water and the effective user price, the greater the loss of water to the economic sink.

The task of demand management is to generate both physical savings of water and economic savings by increasing output per unit of evaporative loss of water; increasing the use of water before it reaches salt sinks; reducing water pollution; reducing the loss of water to the economic sink; and restoring the existing water in the economic sink to use. It is unclear empirically how large each of these potential water savings is, and important research remains to be done on this issue. Definitive estimates of the potential for improving system performance by increasing effective water supply will require basin-specific analyses. There is probably less potential for generating savings from existing systems than nominal system-wide efficiency figures imply. Nevertheless, the potential for generating water savings and economic gains through demand management appears considerable.

POLICY INSTRUMENTS FOR DEMAND MANAGEMENT

The types of policy instruments available for demand management include the following (Bhatia, Cestti, and Winpenny 1995):

(1) Enabling conditions, which are actions to change the institutional and legal environment in which water is supplied and used. Policies here include reform of water rights, privatization of utilities, and laws pertaining to water user associations.

(2) Market-based incentives, which directly influence the behavior of water users by providing incentives to conserve on water use, including pricing reform and

reduced subsidies on urban water consumption, water markets, effluent or pollution charges and other targeted taxes or subsidies.

(3) Non-market instruments, including restriction, quotas, licenses, and pollution controls.

(4) Direct interventions, including conservation programs, leak detection and repair programs, and investment in improved infrastructure.

The precise nature of water policy reform, and the policy instruments to be deployed, will vary from country to country depending on underlying conditions such as level of economic development and institutional capability, relative water scarcity, and level of agricultural intensification. Additional research is required to design specific policies within any given country. However, some key elements of a demand management strategy are the following.

Demand Management for Surface Irrigation

Surface water can be conserved by improving the management of administrative water allocation mechanisms, by using volumetric water prices, or by establishing markets in tradable water rights.

Administrative reforms. Administrative reforms have included modification of water distribution methods (such as shifting from continuous flow to rotational flow water allocation) and institutional reform of public irrigation bureaucracies. Reform of water management methods within existing systems has shown mixed results, with some interventions showing increases in water use efficiency and high rates of economic return (Aluwihare and Kikuchi 1991) and others appearing much less effective (Rosegrant 1989; Rosegrant and Svendsen 1993). It is unclear if real water savings have been achieved through these reforms.

Institutional reform of public irrigation agencies has received increasing attention in recent years and holds considerable promise for long-term progress in improving system performance. Possible reforms include reorganization of irrigation agencies into a semi-independent or public utility mode, applying financial viability criteria to irrigation agencies, franchising rights to operate publicly-constructed irrigation facilities, and strengthening accountability mechanisms such as providing for farmer oversight of operating agencies (Rosegrant and Svendsen 1993).

Water rights, markets, and prices. The primary alternative to quantity-based allocation of water is incentive-based allocation, either through volumetric water prices or through markets in transferable water rights. Many observers have discounted the potential for the use of market-based incentives in water allocation in the Middle East and North Africa, because under Islamic law, water is considered a free resource belonging to the community. However, Islamic law has also long recognized that investment in distribution or conservation of water creates a qualified right to appropriation and sale of water (World Bank 1994).

The empirical evidence shows that farmers are price responsive in their use of irrigation water. The four main types of responses to higher water prices are use of less water on a given crop, adoption of water-conserving irrigation technology, shifting of water applications to more water-efficient crops, and change in crop mix to higher-valued crops (Rosegrant, Gazmuri Schleyer, and Yadav 1995; Gardner 1983).

The choice between administered prices and markets should be largely a function of which system has the lowest administrative and transactions costs. Markets in tradable water rights have two major advantages compared with administered efficiency pricing. First, information costs are reduced, because the market, composed of irrigators with expert knowledge of the value of water as an input in the production process, bears the costs and generates the necessary information on the value and opportunity costs of water. Second, in existing irrigation systems, the value of prevailing usufructuary water rights (formal or informal) has already been capitalized into the value of irrigated land. Imposition of administered pricing is correctly perceived by rights holders as expropriation of those rights, and creates capital losses in established irrigation farms. Attempts to establish administered efficiency prices thus meet with strong opposition from established irrigators, making it difficult to institute and maintain an efficiency-oriented system of administered prices. The establishment of transferable property rights is seen as formalizing existing rights to water rather than expropriating these rights and is therefore politically more feasible (Rosegrant and Binswanger 1994).

Devolution of water rights from centralized bureaucratic agencies to farmers and other water users has a number of advantages. The first is empowerment of the water user, by requiring user consent to any reallocation of water and compensating the user for any water transferred. The second is security of water rights tenure provided to the water user. If well-defined rights are established, the water user can benefit from investing in water-saving technology. Third, a system of marketable rights to water induces water users to consider the full opportunity cost of water, including its value in alternative uses, thus providing incentives to economize on the use of water and gain additional income through the sale of saved water. Fourth, a properly managed system of tradable water rights provides incentives for water users to internalize (or take account of) the external costs imposed by their water use, reducing the pressure to degrade resources.

Establishment of markets in tradable property rights does not imply free markets in water. Rather, the system would be one of managed trade, with institutions in place to protect against third-party effects and negative environmental effects that are not eliminated by the change in incentives. The law establishing tradable water rights should be simple but comprehensive. It should clearly define the characteristics of water rights and the conditions and regulations governing the trade of water rights; establish and implement water rights registers; delineate the roles of the government, institutions, and individuals involved in water allocation and the ways of solving conflicts between them; and provide cost-effective protection against negative third-party and environmental effects that can arise from water trades.

The Chilean water law that created a system of tradable water rights has been successful in dealing with most of these issues. Chile adopted a comprehensive, market-oriented water policy nearly 20 years ago and has had important successes in improving water use efficiency. Tradable water rights in Chile have fostered efficient agricultural use of water, which has in turn increased agricultural productivity, generating more production per unit of water. The market valuation of water at its scarcity value has caused farmers to invest in on-farm irrigation technology that has saved water to irrigate more area or to sell to other uses, has induced a shift to high-valued crops which use less water per unit value of output, and has given farmers greater flexibility to shift cropping patterns according to market demand through the purchase, rent, and lease of water. Because of the topography in Chile, reuse of drainage water is minimal in most river basins, so gains in water use efficiency in agriculture have represented real water savings (Gazmuri Schleyer and Rosegrant 1996).

Demand Management for Groundwater

The problem of overdrafting of groundwater often occurs because individual pump irrigators have no incentive to optimize long-run extraction rates, since water left in the ground can be captured by other irrigators or potential future irrigators. To encourage rational exploitation of groundwater, the same types of policy instruments employed for surface water can be used. The three broad types of institutional arrangements for managing aquifers are quantity-based controls, prices and charges, and tradable water rights (or exchangeable permits) in stocks and flows of groundwater.

Quantity-based controls. Quantity-based control mechanisms include well and pump permits that grant the right to install and operate a well of a particular capacity, and pumping quotas that specify a fixed annual rate of extraction for each water user. Pumping permits for new wells may also impose size and spacing specifications to attempt to optimize extraction rates. Pumping quotas are intended to be more precise and are usually assigned in proportion to water extraction in a base period or based on the proportion of land that is owned overlying the aquifer (FAO 1993).

Prices and charges. Charging pumpers for water can also help control pumping rates. In theory, water prices can be set to include both the direct value of marginal product of the water and the externality cost imposed on other pumpers, thereby inducing each individual pumper to internalize the pumping externalities. Energy prices (for electricity, gasoline, diesel) also influence the profitability and rate of pumping. Subsidies for energy that encourage overuse of groundwater should clearly be removed, but use of selective energy taxes to further reduce pumping rates are likely to cause inefficiencies in energy markets.

Transferable groundwater rights. Well-defined tradable property rights in stocks and flows of groundwater would also promote efficiency, because users would have an incentive to compare the opportunity costs of both different types of water use and current versus. future water uses. The holder of a title to a stock of water could still face increasing extraction costs imposed by the usage rates of other pumpers, but these effects could be reduced with unitization, a contractual arrangement that evolved in oil recovery to mitigate common-pool problems. With unitization, all pumpers contract to use agreed-upon methods of extraction and delivery and to share the costs. Each pumper's share of the lift costs would be based on his or her usage rate, so unitization may entail higher delivery costs, but it would also provide incentives for increased water conservation and thus lower lift costs (Rosegrant and Binswanger 1994).

Managing groundwater in the real world. Government intervention to manage groundwater in the developing world has proven to be difficult to implement, subject to corruption, and in many cases very costly. The most successful tubewell development has been through small-scale private investment, which is widely dispersed and difficult to monitor. Only when private tubewell imports and markets were deregulated did the small-scale tubewell revolution take off in Bangladesh. An attempt at re-regulation through restrictions on well siting slowed growth in tubewell adoption during 1985-1987 (Rogers et al. 1994). Legislation regulating groundwater extraction has been enacted in every country in North Africa, but institutions to enforce the provisions are not adequately developed. In Tunisia, farmers are drilling for alternative sources and are overpumping despite site restrictions, due to the diversion of freshwater supplies to urban and industrial users. Historically, customary rules protected aquifers in most countries in the region from overexploitation, with traditional prohibitions on well digging in the vicinity of an existing well intended to protect both the water supply and capital investment. Advances in pumping technology have, however, overtaken traditional rules, because powerful pumps can draw water from beyond the confines of overlying property and deplete the aquifer they share with other users. When traditional patterns of behavior prove incapable of adjusting to technological changes, alternative governing structures are necessary (USAID 1993).

Are there approaches that can effectively manage groundwater resources in developing countries and reduce the negative effects of overdrafting without imposing unnecessary explicit or implicit taxes on groundwater and stifling the appropriate use of valuable groundwater resources? A big part of the answer to this question comes from an unlikely source, Southern California, where pragmatic, diverse, decentralized, and to a large extent successful approaches to groundwater management have evolved over time as water users and local governments have responded to depletion of groundwater resources and degradation of the environment. Groundwater management programs have eliminated overdrafts, impounded surface and imported water for aquifer replenishment, and stopped saltwater intrusion (Blomquist 1995).

The law governing California groundwater resources does not seem promising for efficient exploitation of the water, because of the potentially contradicting principles embedded in the law. Four principles govern groundwater rights:

(1) Overlying landowners have rights to the reasonable use of groundwater on their land.

(2) Relative to each other, overlying land owners have correlative rights to water, and would share proportionately in water supply reductions in the event of shortages.

(3) Appropriators (those pumping water who did not own overlying land) have a seniority system with respect to one another, with reductions in water use imposed first on junior rights holders.

(4) Overlying owners have first rights to the amount of water that constitutes reasonable use; appropriators have a right to the surplus remaining, if any (Blomquist 1992).

These principles allow substantial room for interpretation, but California water law also calls for adjudication of groundwater rights among all users in a basin or aquifer when disputes over these rights occurs. Adjudication generally is initiated when one or more rights holders believe that their rights are being impaired by a lowering of the water table or contamination of the water.

The adjudication process results in a governance structure for the water basin that establishes water rights, monitoring processes, means for sanctioning violations, representative associations of water users, financing mechanisms for the governance system, and procedures for adapting to changing conditions (Blomquist 1992). Central to the governance structure is a water management program that has employed a variety of the instruments described (and combinations of instruments) in different basins to influence water demand, including pumping quotas (usually based on some notion of historical use), pumping charges, and transferable rights to groundwater.

The features that have made this governance structure for groundwater management efficient in many of the basins in Southern California also make it highly appropriate for developing-country conditions. Key elements for the success of this governance structure are that it is agreed upon and managed by the water users; it is responsive to local conditions; it operates with available information and data bases, rather than requiring theoretically better but unavailable information; and it adapts to the evolving environment.

The proper role for government is also suggested by a characteristic that is both a strength and weakness of groundwater management procedures in California. Changes in groundwater management are not imposed, or even considered, unless a management problem exists, thus preventing interventions that can derail the efficient use of groundwater. The negative side is that the move toward solutions often does not begin until significant damage to the groundwater resource has been done, in large part because of the difficulty of obtaining information about the state of the aquifer. The government can therefore play an important role in monitoring the groundwater resource to identify emerging problems and in facilitating an institutional environment that is conducive to decentralized solutions.

Privatization and User Participation in Irrigation

The importance of user participation in and management of irrigation has been mentioned repeatedly. Involvement of farmers in the development and management of even large-scale irrigation systems is desirable from the project planning and design stage. Financial participation by future water beneficiaries in investment in new infrastructure would also be helpful. User participation in the approval and financing of infrastructure corrects inappropriate investment incentives in the public sector, which often lead to the construction of unprofitable infrastructure and continuing large capital and operating subsidies financed through tax revenues. Large subsidies in turn have often meant transferring resources from the poorest sectors of the population (who usually do not have subsidized water and who spend a large percentage of their incomes on sales or value-added taxes), to the better-off who receive subsidized water.

Turnover of irrigation systems. In many African countries, the devolution of irrigation infrastructure and management to water user associations (WUAs) could be beneficial, but there is little experience with system turnover. In some public irrigation systems, for example in Egypt, Morocco, and Tunisia, WUAs are being promoted, but the roles of user associations have been generally limited to operations and maintenance of tertiary canals. Some evidence exists on the benefits of increased farmer participation in Senegal. Before devolution of responsibilities from the government agency to farmer organizations, farmers paid little if anything toward operations and maintenance and the irrigation agency acted on an irregular basis. Irrigation services were unreliable, and overpumping had led to salinization. After taking over the systems, farmers paid higher irrigation rates to cover full operations and maintenance costs, water delivery performance improved markedly, and electricity costs were decreased through more careful monitoring of pumping, because farmers had both the incentive and the ability to control the amount of overpumping (Meinzen-Dick, Reidinger, and Manzardo 1995).

Turnover of schemes (or parts of schemes) in Africa could also benefit from the experiences elsewhere in the developing world. In the past, turnover of irrigation infrastructure and system management has often failed, because of flaws in internal structural features or external factors which affect the viability and sustainability of WUAs in managing irrigation systems. A recent review has identified some of the characteristics that appear to be associated with successful WUAs. WUAs tend to be stronger if they build upon existing social capital or patterns of cooperation. Groups are likely to be stronger if they are homogeneous in background and assets, although heterogeneity can be managed. WUAs must have a demonstrable effect in improving water control and farm profitability to ensure that the benefits to farmers outweigh the costs of participation. Particularly crucial to success is a supportive policy and legal environment that includes the establishment and adjudication of secure water rights, monitoring and regulation of externalities and third-party effects of irrigation, and provision of technical and organizational training and support (Meinzen-Dick et al. 1997).

Reforming Urban Water Systems

Urban areas can be important sources of water savings, and the primary locations for improving water quality. More than 20 percent of the world's population lives in urban areas along coastlines. Almost all of the water utilized in these cities drains directly into the ocean salt sink without any reuse, so both reduced initial consumption and reduced wastage in the distribution system will be translated directly into real physical water savings (Seckler 1996). In most noncoastal cities in developing countries, reuse of drainage water is also minimal because of the absence or poor quality of treatment facilities, and what water is reused poses serious health hazards. Under these conditions, reduced consumption and transmission losses will also represent real gains in water availability.

The amount of water wasted and lost in urban distribution systems, homes, commercial establishments, and public facilities is often huge. Aside from Cairo, where water losses were around 50 percent in 1989/90, data on water losses in the large metropolitan areas of Africa are limited, but it is likely that water losses are comparable to those elsewhere in the developing world (Abu-Zeid 1992). Nonagricultural water demand requirements in Manila were estimated at 1,285 million cubic meters in 1995, 204 million cubic meters more than is available from secure groundwater yields and dependable surface water flows, leading to serious overdrafting of aquifers. Only 42 percent of water supplied, however, was actually sold to users. Thus, fully 58 percent of supply was unaccounted-for water, consumed by "illegal" users and lost during distribution (Ebarvia 1995). The average level of unaccounted-for water in World Bank-assisted urban water projects is about 36 percent. Barranquilla, Jakarta, Lima, and Mexico City have unaccounted-for water levels as high as 60 percent, compared with 10-15 percent in well-managed systems. Although some of this unaccounted-for water is unreported water use by public agencies or unauthorized private use, much of it is losses into the soil or salt sinks. In Jakarta, for example, water loss through leakage has been estimated at 41 percent of total supply. It has also been estimated that nearly one-half of these losses can be eliminated cost-effectively (Bhatia and Falkenmark 1993).

Pollution of water from industrial effluents, poorly treated or untreated domestic and industrial sewage, runoff of agricultural chemicals, and mining wastes constitute a growing problem. The main contaminants found in water include detergents (soaps and solvents), pesticides, petroleum and other derivatives, toxic metals (for example lead and mercury), fertilizers and other plant nutrients, oxygen-depleting compounds (e.g. wastes from canneries, meat-processing plants, slaughterhouses, and paper and pulp processing), and disease causing agents responsible for hepatitis and infections of the intestinal tract such as typhoid fever, cholera, and dysentery (Anton 1993). Unsafe drinking water, combined with poor household and community sanitary conditions, is a major contributor to disease and malnutrition, particularly among children. Contaminated wastewater is often used for irrigation, creating significant risks for human health and well-being.

Water quality problems, common throughout Africa, are typified by the situation in Egypt, where a high percentage of wastewater is untreated and discharged into the Nile, irrigation canals, and drainage ditches. A study of 66 agricultural drainage canals estimated that they carried an annual discharge of 3.2 billion cubic meters of wastewater, including raw sewage from villages, semi-treated or untreated wastewater from Cairo and other urban centers, and mostly raw sewage from the rapidly growing unserviced periurban areas (Abu-Zeid 1992).

The poor performance of urban water systems are in significant part due to flawed policies. When incremental water can be obtained at low cost as a result of subsidies there is little incentive to improve either physical efficiency (by, for example, investment in pipes or metering) or economic efficiency (collection of water tariffs). Considerable evidence shows that the use of incentive-based policy instruments can achieve substantial water savings and improve the delivery of services, as well as water quality. These instruments have been used to raise efficiency and generate savings in urban water service and delivery, household water use, and industrial water use.

Urban water services. Urban water supply in most of Africa is controlled by theoretically independent public authorities. These authorities are often controlled by the government in essential matters, such as fee setting, personnel management, and investment policies, and their privatization could reap substantial benefits. In Chile, for example, privatization and the granting of secure water rights held by the urban water companies, together with an active water market, have encouraged the construction and operation of improved treatment plants that sell water for urban use. Efficiency in urban water and sewage services has been greatly increased with no significant impact on prices. The coverage of potable water has risen to 99 percent in urban areas and 94 percent in rural areas from 63 percent and 27 percent respectively before the reforms (Gazmuri Schleyer and Rosegrant 1996).

Privatization of urban water services has also been highly effective in Africa. Urban water services in Côte d'Ivoire have been operated by a private company, Société de Distribution d'Eau de Côte d'Ivoire (SODECI), under a mixture of concessions and lease contracts, since 1960. SODECI was established as a subsidiary of a large, French water utility to operate the water supply system of Abidjan and is now majority-owned by Ivorian shareholders. This arrangement performed well in many ways. In 1989, 72 percent of the urban population had access to safe water, compared with 30 percent in 1974. About 80 percent of the rural population was served by water points equipped with hand pumps, compared with 10 percent in 1974. The operating efficiency in urban areas is high, with unaccounted-for water at 12 percent and the collection rate for private consumers at 98 percent (World Bank 1993).

Despite the success of privatization in many cases around the world, in much of Africa, it has proven difficult to even establish full autonomy for public water authorities, particularly for personnel, water tariffs, and investment programming and financing, due to the reluctance of governments to relinquish influence. Given these difficulties, it may be appropriate to adopt phased approaches to privatization of urban water services, using options such as concession arrangements, service or management contracts, or build, operate, and transfer schemes (World Bank 1994).

Household consumption. Removal of subsidies in urban water use can have dramatic effects on water use. An increase in the water tariff in Bogor, Indonesia, from US$0.15 to US$0.42 per cubic meter resulted in a 30 percent decrease in household demand for water. It is likely that this degree of price responsiveness is typical for household demand in much of Africa, although evidence is limited (Bhatia and Falkenmark 1993). A considerable body of analysis for developed countries shows a central range of price elasticities of demand for household water of -0.3 to -0.7 (Frederick 1993). There have been few studies of household demand elasticities in developing countries because water tariffs have generally been low, price changes have not been significant, and metering has been absent. However, the limited available evidence is consistent with the estimated values for developed countries. In Brazil and Mexico, estimated price elasticities for urban water demand are -0.60 and -0.38, respectively (Gomez 1987).

Industrial water use. Experiences in Japan and the United States show that increased water prices, effluent charges, and pollution regulations have great potential to generate industrial water savings by promoting investment in water recycling and water conservation technology. Increased water tariffs induced a 50 percent reduction in water use over a six-year period by a fertilizer factory in Goa, India. In São Paulo, Brazil, three industries reduced water consumption by 40-60 percent in response to the establishment of effluent charges. In Israel, water consumption per unit value of industrial output dropped by more than two-thirds from 1962 to 1982. These dramatic improvements were achieved through the issuance of restrictive water licenses, the introduction of water-saving technologies, and subsidized financing for investment in water-saving processes (Bhatia and Falkenmark 1993).

A legal basis for controlling water pollution already exists in all North African and several Sub-Saharan Africa countries, but the laws and regulations have mostly been unenforceable. In Egypt, the law established stringent effluent standards for various organic and inorganic pollutants, but water quality standards were too rigid. The regulations gave no consideration to the country's economic, social, and technological conditions or implementation requirements, such as the institutional arrangements, availability of adequate funds, trained manpower, and sophisticated laboratories for analyses, monitoring, inspection and enforcement. As a result, dispensations were granted to polluters, many of them public-sector companies, since it was not possible for them to comply with the regulations (Abu-Zeid 1992). More realistic regulations, preferably relying on incentives rather than restrictions, are urgently needed in the region to arrest the degradation of water quality.

CONSERVATION THROUGH APPROPRIATE TECHNOLOGY

If improved demand management introduces incentives for generating water savings, availability of appropriate technology will be an essential component for generating water savings. As the value of water increases, the use of more advanced technologies, such as drip irrigation utilizing low-cost plastic pipes, sprinklers, and computerized control systems, used widely in developed countries, could have promising results in the region, particularly in the water-scarce North African and Sahelian countries.

Any evaluation of the impacts of these technologies must take account of the difference between consumptive use of water and water withdrawals or applications. All of these advanced technologies can significantly reduce the amount of water applied to a field, but, to the extent that the saved water simply reduces the amount of drainage water that is reused, the actual water savings will be lower than the apparent efficiency gains.

Nevertheless, if the scarcity value of water is high enough, appropriate use of new technologies appear to offer both real water savings and real economic gains to farmers.

Field application efficiencies in flood irrigation in developing countries are typically in the range of 40-60 percent. High-pressure sprinklers save on drainage losses but may not reduce consumptive use because of the high evaporative losses. Modern low-pressure, downward-sprinkling systems, however, can reduce evaporation considerably (Seckler 1996). Surge irrigation can reduce water applications significantly. Instead of releasing water continuously down field channels, surge irrigation alternates between rows at specific intervals. The initial wetting of the channel partially seals the soil and allows water to be distributed more uniformly, reducing percolation, runoff, and evaporation. Drip irrigation offers perhaps the greatest potential benefits in real water savings. By directing water applications directly to the root zones, drip irrigation can significantly reduce field evaporation losses. Drip irrigation can also increase the productivity of water in areas already affected by salinity. Used in conjunction with tubewells, these systems can lower water tables and leach salts below the root zone of plants (Seckler 1996).

Technological opportunities also exist at the irrigation system level. In Malaysia's Muda irrigation system, real-time management of water releases from the dam, keyed to telemetric monitoring of weather and streamflow conditions, has significantly improved water use efficiency and reduced drainage to the ocean. In North Africa, modern irrigation systems using hydraulically operated diversion and measuring devices were developed as early as the late 1940s and were employed in irrigation schemes constructed in the 1950s. Modern schemes in this region deliver water on demand to individual farmers, allowing water users to be charged according to the volume of water delivered, encouraging conservation and efficient water use. Some of these irrigation techniques have been transferred to the Middle East and in pilot projects to other developing countries (World Bank 1993). Continued increases in the value of water could make these capital-intensive irrigation distribution systems more widely feasible in other regions of the world.

ENVIRONMENTAL DEMANDS FOR WATER

Many aspects of environmental protection and improvement of water quality have already been discussed. Demand management instruments such as development of appropriate legal and institutional frameworks, regulatory policy, and incentive policies can promote environmental sustainability and water quality through recycling, reduction of excess water application in saline areas, and elimination of groundwater overdraft. In many of the critically important aspects of water resource strategy, the goals of water use efficiency and conservation, economic efficiency, and environmental sustainability are fully complementary.

In other ways, however, as countries grow and incomes increase, environmental demands for water may increasingly compete with the use of water for directly productive purposes in agriculture, household, and industrial sectors. California shows the potential for competition among different uses. Instream flows and runoff are legally mandated for a variety of environmental purposes, including preservation of wild and scenic rivers, protection of endangered fish and wildlife species, and prevention of salt water intrusion. Between 1960 and 1990, urban water use in California rose from 2.5 cubic kilometers to 7.4 cubic kilometers, and water use in irrigated agriculture also increased, from 24.7 cubic kilometers to 29.6 cubic kilometers, while legally mandated natural runoff for environmental purposes increased from 1.2 cubic kilometers to 29.6 cubic kilometers, or 28 percent of total water supply.

As incomes grow in developing countries, there will be significant increases in the demand for environmental "goods," including demand for direct allocation of water for environmental purposes. The amount of water required to simply prevent salt water intrusion and to flush and dilute salts and pollutants from rivers and irrigation canals will also increase rapidly, particularly if countries fail to reform demand management policies. In addition to dealing with the environmental concerns arising from urban and industrial use of water, direct environmental demands for water will need to be accommodated, together with urban and agricultural water demands. The evidence shows that effective environmental protection policies can be designed, but in the final instance, in any society, how much environmental protection will be provided will be a matter of political choice and commitment.

12. CONCLUSIONS

The evidence suggests that meeting the challenges of food security and water scarcity in Africa will require both selective development and exploitation of new water supplies and comprehensive policy reform that encourages more efficient use of existing water supplies. The most appropriate mix of supply augmentation and demand management, and the most feasible institutional arrangements and policy instruments will vary depending on a region's level of development, agroclimatic zones, relative water scarcity, level of agricultural intensification, and degree of competition for water.

Highly selective, economically efficient development of new water can involve impoundment of surface water and sustainable exploitation of groundwater resources, as well as expanded development of nontraditional water sources. The full social, economic, and environmental costs of development must be considered, but so must the costs of failure to develop new water sources. Project design must ensure comprehensive accounting of costs and full benefits, including not only irrigation benefits, but health, household water use, and catchment improvement benefits.

Irrigation development will not be the main source of food production growth in Africa, but increased investment in irrigation could have an important role in reducing projected cereal import demands. Historical experience shows not only failures in both large- and small-scale irrigation projects, but also provides examples of success stories and lessons that can assist in identifying relevant investment strategies. Because of the difficult physical environment and relatively high investment costs, especially in Sub-Saharan Africa, effective project design and implementation are absolutely essential to achieving acceptable rates of return.

The evidence indicates that, fundamentally, the small versus large distinction is not very useful in the African context. It is not the size of the irrigation system that determines its success, but the interaction of institutional, physical, and technical factors. One of the most important contributors to success is enhanced farmer participation in project design, development, and management of irrigation. Priority should be given to indirect investments, in the form of grants, loans, and technical expertise, for expansion of farmer-controlled small-scale projects, especially in countries and regions with poor potential for rainfed agriculture. This expansion would have the additional benefit of acquisition of experience, not only with respect to the proposed technologies, but also with respect to the economic, social, and institutional aspects of implementation.

Rehabilitation and improvement of existing irrigation systems can be an attractive option, but projects must be selected carefully. Investments in rehabilitation and modernization should be used to provide incentives for management reform in existing bureaucratically-run irrigation systems. Without such reform, it will be unlikely that the benefits from rehabilitation will be adequate to justify the investments. Promising reforms include the reorganization into a semi-independent or public utility mode, applying financial viability criteria to irrigation agencies, franchising rights to operate publicly-constructed irrigation facilities, and strengthened accountability mechanisms such as providing for farmer oversight of operating agencies.

Governments should sharply increase investment in exploration and evaluation of aquifers and soils to determine the extent of groundwater storage and recharge. Expanded government efforts to extend and disseminate groundwater and well irrigation technologies and techniques should have a high payoff. Pilot schemes in groundwater development could assist in the development and dissemination of appropriate designs.

Because of the rapidly growing water scarcity and heightened competition for water among alternative uses, comprehensive water policy reform is urgently needed in North Africa, and will be increasingly important for the relatively water-scarce countries of Sub-Saharan Africa as economic development is rekindled. Demand management will be essential for saving water in existing uses, increasing the economic efficiency of water use, for improving water quality, and for promoting environmentally sustainable water use. The most significant reforms will involve changing the institutional and legal environment in which water is supplied and used to one that empowers water users to make their own decisions regarding the use of the resource, while at the same time providing a structure that reveals the real scarcity value of water, including environmental externalities. Key elements of these reforms include establishment of secure water rights to users; decentralization and privatization of water management functions; and the use of incentives including markets in tradable property rights, pricing reform and reduction in subsidies, and effluent or pollution charges. Nonmarket instruments such as licensing and regulation, and direct interventions such as conservation programs can also play an important role. Decentralization of management and adoption of incentive-based water allocation will prove successful when agreed upon and managed by the water users, when responsive to local conditions, when operated with available information and data bases, and when adaptive to the evolving environment.

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